FRDA Report 105

SITE PREPARATION
A Swedish Overview

ECONOMIC & REGIONAL DEVELOPMENT AGREEMENT

Canada

BC

Site Preparation: A Swedish Overview

by
G. Örlander [1], P. Gemmel [1] and J. Hunt [2]

[1] Southern Swedish
Forest Research Station
Swedish University of
Agricultural Sciences
Box 49
S-230 53 Alnarp
Sweden

[2] 9038 Wilberforce St.
Burnaby, B.C.
Canada
V3N 4C6

February 1990

90-04424/

Funding for this publication was provided by the Canada-British Columbia Forest Resource Development Agreement - a five year (1985-90) $300 million program cost-shared equally by the federal and provincial governments.

Canadian Cataloguing in Publication Data

Orlander, G.
Site preparation, a Swedish overview

(FRDA report, ISSN 0835-0752 ; 103)

Issued under Canada-BC Forest Resource Developmen. Agreement.
Co-published by B.C. Ministry of Forests.
"Canada/BC Economic & Regional Development Agreement."
Includes bibliographical references.
ISBN 0-7726-1081-9

1. Forest site quality - Sweden. 2. Forest soils - Sweden. 3. Forest productivity - Sweden. 4. Reforestation - Sweden. I. Gemmel, P. II. Hunt, J.A. (James A.), 1957- III. Canada. Forestry Canada. IV. British Columbia. Ministry of Forests. V. Canada-British Columbia Forest Resource Development Agreement. VI. Canada/BC Economic & Regional Development Agreement. VII. Title. VIII. Series.

SD391.074 1990 634.9'56 C90-092065-3

© 1990 Government of Canada,
Province of British Columbia

This is a joint publication of Forestry Canada and the British Columbia Ministry of Forests.

Produced and distributed by the Ministry of Forests, Research Branch.

For additional copies and/or further information about the Canada-British Columbia Forest Resource Development Agreement, contact:

Forestry Canada
Pacific Forestry Centre
506 West Burnside Road
Victoria, B.C. V8Z 1M5
(604) 388-0600

or

B.C. Ministry of Forests
Research Branch
31 Bastion Square
Victoria, B.C. V8W 3E7
(604) 387-6719

ABSTRACT

This report is a translation of a Swedish paper on the biological aspects of site preparation. A brief introduction comparing the forestry conditions in British Columbia and Sweden has been added.

Problems concerning reforestation are discussed. Factors influencing forest production, and the effect of site preparation on these factors, are presented. These factors include soil temperature, density, and moisture; relative humidity; gas exchange in the soil; and soil nutrients. Causes of mortality include frost heaving, pine weevil infestation, frost damage, and vegetative competition. The effects of site preparation on these causal agents are reviewed. As well, several site preparation methods and planting without site preparation are examined; and stand establishment methods on old fields and peatlands are summarized. Site preparation in relation to natural regeneration, sowing, and different stock types is also presented.

ACKNOWLEDGEMENTS

This report was translated and adapted with the permission of the Swedish Silviculture Society Journal (S.S.T.). The authors wish to thank Lorne Bedford of the B.C. Ministry of Forests for his energetic support; Dave Spittlehouse of the B.C. Ministry of Forests for his technical review of the english edition; and Gunnel Brännström and Marika Hedlund for assistance with the graphics. Dave Butcher of T.D. Mock & Associates is responsible for the excellent layout of the text and figures.

Funding for the report was provided under Project 1.10 of the Forest Resource Development Agreement (FRDA) and the Silviculture and Research Branches of the B.C. Ministry of Forests.

TABLE OF CONTENTS

ABSTRACT iii

ACKNOWLEDGEMENTS iv

INTRODUCTION 1

A Comparison of Swedish and British Columbian Forests and Silviculture 2

1 SPECIAL PROBLEMS WITH REFORESTATION 5

2 PRODUCTION FACTORS 7

2.1 Soil Temperature: Seedling Reaction 7
2.2 Soil Temperature: Effect of Site Preparation 8
2.3 Soil Density: Seedling Reaction 10
2.4 Soil Density: Effect of Site Preparation 11
2.5 Relative Humidity: Seedling Reaction 12
2.6 Relative Humidity: Effect of Site Preparation 13
2.7 Soil Moisture: Seedling Reaction 13
2.8 Soil Moisture: Effect of Site Preparation 15
2.9 Gas Exchange in the Soil: Seedling Reaction 16
2.10 Gas Exchange in the Soil: Effect of Site Preparation 18
2.11 Soil Nutrients: Seedling Reaction 18
2.12 Soil Nutrients: Effect of Site Preparation 19

3 MORTALITY CAUSES 21

3.1 Frost Heaving 21
3.2 Frost 23
3.2.1 Seedling reaction 23
3.2.2 Effect of site preparation 24
3.3 Pine Weevil 26
3.4 Vegetation 26
3.4.1 Seedling reaction 26
3.4.2 Effect of site preparation 27
3.5 Allelopathy 29

4 SITE PREPARATION METHODS 31

4.1 Planting Without Site Preparation 31
4.2 Scarified Patch and Disced Trench 32
4.3 Mounding or Elevated Berm 33
4.4 Mounding On Mineral Soil or Humus 34
4.5 Mound Size and Planting Spot 35
4.6 Plowing 36
4.6.1 Plowing: the debate continues 37
4.7 Berm Formation and Planting Spot 38
4.8 Deep Plowing and Complete Plowing 39

5 SITE PREPARATION ON SPECIAL SITE TYPES 41

5.1 Old Fields 41
5.2 Peatlands 41

6 SEEDLING STOCK 43

6.1 Stock Size 43

6.2 Species 43
6.3 Mycorrhizae 44

7 NATURAL REGENERATION AND SOWING 45

8 LONG-TERM EFFECTS OF SITE PREPARATION 47
8.1 How Strong is the Proof? 49

LITERATURE CITED 51

APPENDICES

1 Comparison of the climatic zones in British Columbia and Sweden using the Köppen-Geiger system of climate classification 59

2 Schematic descriptions of site preparation methods 60

INTRODUCTION

This report is a translation of a Swedish publication (Örlander and Gemmel 1989) that summarizes the knowledge on site preparation, concerning biological questions on seedling establishment and growth. A section has been added to this introduction to familiarize forest managers in British Columbia with Swedish ecological and silviculture conditions. The aim of the report is to provide a basic educational aid on stand establishment. The references cited could be used for more advanced studies. Göran Örlander of the Southern Swedish Forest Research Station is the main author.

Site preparation is carried out mainly to create a good environment for the establishment and growth of seeds and seedlings, as well as to facilitate practical reforestation work. This report is concerned primarily with the biological aspects of site preparation, that is, what seeds and seedlings need in their environment and how favourable environments can be created to meet these requirements. Mechanized and manual site preparation are the main methods dealt with in this report. Chemical and prescribed burning methods are discussed in less detail.

Knowledge of site preparation dates back to the time that man began to cultivate forests. Burning, for example, has long been used with natural and artificial regeneration. Many of the methods that are becoming increasingly common have been proven long ago. Wahlgren (1914), for example, described both planting in mineral soil mounds and planting in inverted humus mounds (Figure 1).

The difference between the early knowledge and what is known today is that research has given us a better understanding of the biological processes and factors that influence seedling survival and growth. Today we also have the technological capability to carry out varied forms of site preparation.

The clearcutting silvicultural system used today in Sweden came into practice at the beginning of the 1950's. At this time, prescribed burning was the dominant site preparation method used for both artificial and natural regeneration (Figure 2). Technical developments in site preparation occurred at the end of the 1950's, at the same time as prescribed burning came under environmental criticism (Bäckström 1986). This increased interest in site preparation resulted in many studies (e.g., Bärring 1965). Plowing (tilt), developed in Finland during the 1960's, was used opera-

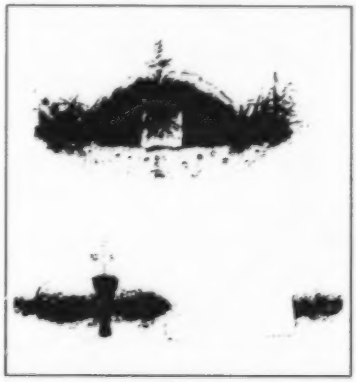
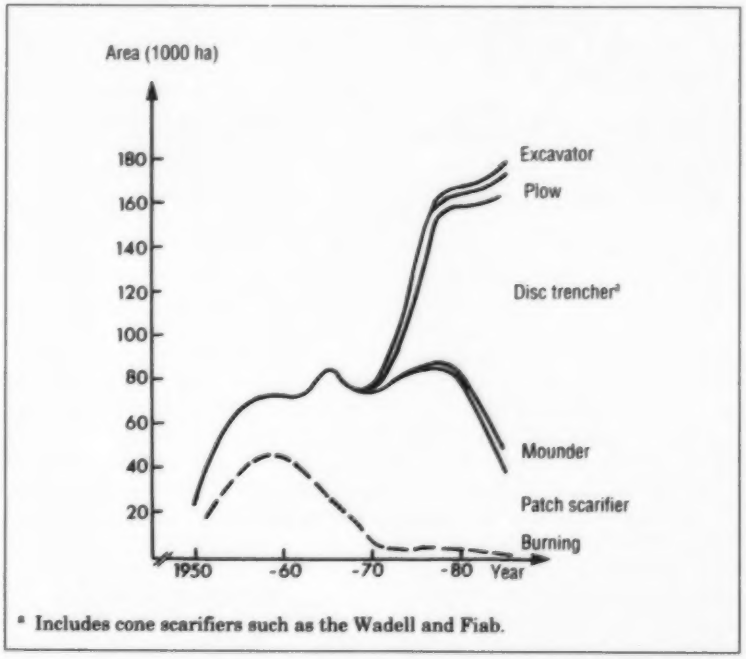


FIGURE 1. The "modern" site preparation methods are described in old silviculture books. Wahlgren (1914) describes, among other things, a technique similar to planting plug stock in a mineral soil mound (above) and planting with a hoe in inverted humus.



[a] Includes cone scarifiers such as the Wadell and Fiab.

FIGURE 2. The forest area in Sweden site-prepared with different methods during the period 1950-1985 (after Adelsköld [unpublished]). Areas treated with each method are stacked (e.g. in 1979, of the total hectares treated, approximately 2500 ha were treated by excavator). Burning and patch scarification were used during the 1950's and 1960's. Disc trenching, plowing, and mounding have developed during the last 20-year period.

tionally in Sweden at the beginning of the 1970's. Many empirical studies of site preparation were carried out during the 1970's. For example, factors affecting establishment and growth were described by Söderström (1976a), among others; and Lundmark (1977) warned about excessively harsh site preparation methods and consequent reductions in stand productivity from nutrient leaching. At the same time, site preparation technology such as mounders and power-driven disc trenchers was developed, which allowed methods to be more closely adapted to site types.

In recent years, research has developed further to include such aspects as physiological growth studies of seedling establishment (e.g., Örlander 1984) and temperature effects (e.g., Lundmark 1982) following site preparation. A 1986 report (Bäcke *et al.*) discusses theoretical applications of site preparation principles for different site types.

A Comparison of Swedish and British Columbian Forests and Silviculture

Translation of this report was undertaken so that British Columbia forest managers could benefit from Fennoscandian experience. The forests and silviculture of British Columbia and Sweden share many similarities that enable forest managers to benefit from an exchange of information and equipment. There are, however, also many biological, technical, social/political, and economic constraints that affect the transfer of technology. Before Swedish technology can be effectively adapted to British Columbia it is essential to have some understanding of Swedish forestry conditions. The site-specific nature of reforestation demands treatments that are adapted to local conditions.

This section describes some of the main similarities and differences between Swedish and British Columbian forestry.

Sweden and British Columbia have many climatic similarities. Köppen's climatic system of classification shows three climatic regions common to British Columbia and Sweden. These include two humid continental regions with cold, snowy climates, moist all year with cool summers (Dfc) and warm summers (Dfb); and one marine west coast region that has a temperate, rainy climate with warm summers (Cfb) (Strahler 1975).

Krajina (1969) indicates that the ESSF, BWBS, and SBS biogeoclimatic zones fall within Köppen's Dfc region and that the ICH and CWH zones fall into the Dfb (Dfc) and Cfb regions, respectively. The SBPS has been recently split from the SBS. In Sweden, the Dfc region extends north from central Sweden; the Dfb region is in the central part of the country, and the Cfb region is in the south (see Appendix 1) (Strahler 1975).

Eastern Sweden is relatively dry in the early summer. Similar moisture deficits where potential evaporation exceeds precipitation can occur in the drier subzones of the SBS (D. Spittlehouse, B.C. Ministry of Forests, pers. comm.).

Further comparisons for temperature and precipitation of appropriate biogeoclimatic zones in British Columbia and Sweden can be made from Table 1 and Figure 3. There are, however, many other ecological factors besides climate that affect the similarity of ecosystems.

In Sweden, the invasion of species following the last glaciation 10 000 years ago has not been as rapid as in North America and so ecosystems are less diverse. The main forest species are Scots pine (*Pinus sylvestris*), Norway spruce (*Picea abies*), and birch (*Betula pendula, B. pubescens*). Several other broadleaved species occur in the south. The proportionate volumes of pine, spruce, broadleaved, and dead wood are 37:46:15:2%, respectively (Skogsstyrelsen 1989). An average of 33 000 ha/yr have been planted with *Pinus contorta* since 1980. Average forest productivities in the boreal forests of British Columbia and Sweden are comparable and vary from 2.9 m^3/ha per year in the north to 8.4 m^3/ha per year in the south of Sweden (Skogsstyrelsen 1989).

TABLE 1. Range of average maximum and minimum T-sums and precipitation amounts received from May to September in British Columbia (after Reynolds [1] [unpublished data])

Zone[a]	T-sum[b]		Precipitation (mm)	
	Max	Min	Max	Min
ESSF	801	629	425	205
SWB	933	534	443	254
SBPS	1044	697	300	243
BWBS	1268	709	305	145
SBS	1510	884	353	189
ICH	2140	1267	439	200
CWH	2205	1059	1162	159

[a] ESSF=Englemann Spruce - Subalpine Fir; SWB=Spruce - Willow - Birch; SBPS=Sub-Boreal Pine - Spruce; BWBS=Boreal White and Black Spruce; SBS=Sub-Boreal Spruce; ICH=Interior Cedar - Hemlock; CWH=Coastal Western Hemlock.

[b] Accumulated daily mean temperatures exceeding the threshold value of 5° C. (e.g. a day in June with a mean temperature of 18° C contributes 13° C to the T-sum).

Swedish soils are relatively shallow and less diverse than those in British Columbia (Hunt and McMinn 1988). They are mostly morainal with a high frequency of stones. Roughly 29% of the productive forest land in Sweden has fine-textured (<0.06 mm) soils (Bäcke *et al.* 1986). Some soils commonly referred to as fine-textured in Sweden, (e.g., fine sand, fine sandy-silt)

[1] Reynolds, G. 1989. Climate data summary for biogeoclimatic zones. Unpublished report, B.C. Ministry of Forests, Research Branch, Victoria, B.C.

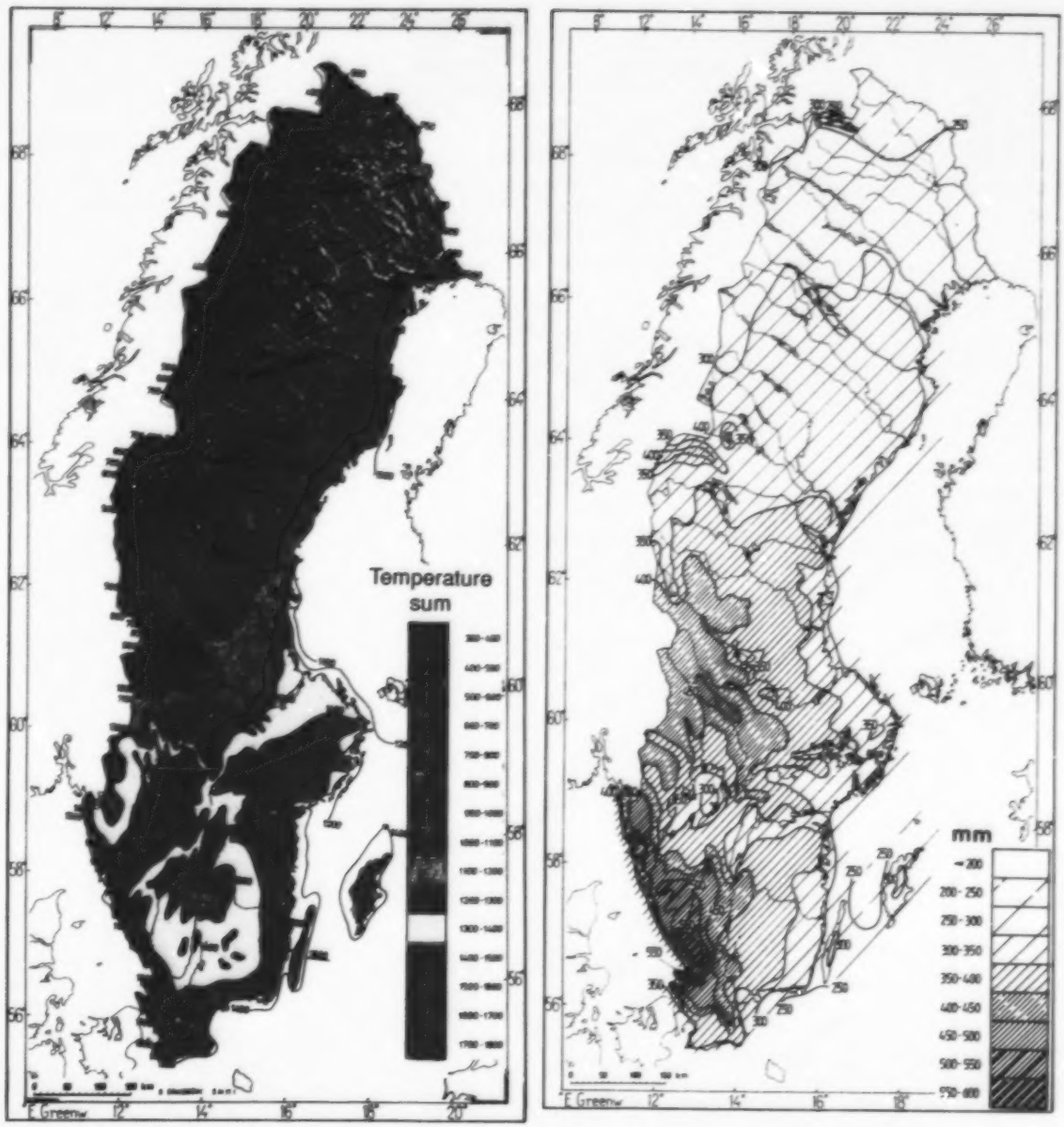


FIGURE 3. Swedish temperature sums (threshold value 5° C) during the growing season(left) (after Odin et al. [1983]), and precipitation received from the start of the growing season until October 1 (right) (after Eriksson [1986]).

may be coarser than the soils commonly called fine-textured in the Interior of British Columbia.

Soil densities in British Columbia and Sweden are generally comparable, with high densities occurring in Swedish morainal soils and in British Columbia interior subsoils (M. Osberg, B.C. Ministry of Forests, pers. comm.).

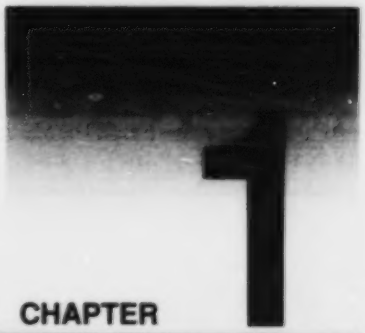
Reforestation problems in British Columbia and Fennoscandia have some differences. The pine weevil (*Hylobius abietis*), for example, is a serious threat to stand establishment in Fennoscandia, but is not found in British Columbia. Other weevil species such as Warren's root collar weevil (*Hylobius Warreni*) are found in British Columbia but do not pose a serious threat to stand establishment. In Sweden, exposure of mineral soil has been an important means of reducing pine weevil damage.

Problems with non-crop vegetation are usually more intense in British Columbia than in Sweden. As well, Swedish utilization standards are high and harvesting is concentrated in managed stands, so slash loadings are very low compared to those in British Columbia.

Sweden has a long history of intensive reforestation practices, in addition to a strong research mandate. Management and silviculture regimes in the country differ notably from those in British Columbia. Land ownership in Sweden is predominantly private and there is incentive to manage intensively. Legislation is comprehensive and detailed (e.g., stand thinning heights and basal areas are stipulated by site index). Ground applications of herbicides are still legal in Sweden though they are not used operationally because municipal permission must be obtained and chemical treatments in the forest are unpopular with the public. A more detailed discussion of silviculture and forest management in Sweden is presented by Hunt and McMinn (1988).

SPECIAL PROBLEMS WITH REFORESTATION

- *Recently planted seedlings are usually impaired by water stress. Site preparation can create an environment for the seedling which reduces this stress.*
- *Different types of damage, by frost and insects for example, can be reduced by site preparation.*



CHAPTER 7

Any kind of plant cultivation requires some maintenance to achieve a successful result. Forest planting entails several problems which do not occur in your backyard garden. These problems may involve the transport and handling of seedlings, or the lack of opportunity to care for seedlings following planting. During the transport of seedlings, light, moisture and temperature relations change. Recently planted seedlings commonly sustain reduced needle and shoot growth (planting check), partly as a result of water stress incurred during planting. Recently planted seedlings have a reduced capacity to take up water (Figure 4). This influences their survival as well as their growth.

Örlander's (1986a) experiment showed that the water uptake of planted seedlings was only 10% compared to that of established seedlings in the same clearcut. Usually there is no water deficit on a fresh (subhygric to mesic) site type.

The frost hardiness of nursery grown seedlings may be significantly impaired during the first season after outplanting (Rosvall-Åhnebrink 1985) (cf. Strathers 1989). Another problem is the change in light regime when a seedling is removed from the densely crowded nursery to a bright clearcut. Norway spruce, for example, is especially sensitive to this change in light (Lindell 1982).

Common causes of mortality following planting are high soil moisture, pine weevil (*Hylobius abictes*), frost, grass competition and frost heaving (National Board of Forestry 1986). These causal agents can also be affected by the choice of site preparation method.

Site preparation should provide an environment that moderates the stress associated with planting. In Sweden, it is mostly soil temperature and soil moisture that is affected by site preparation (Söderström 1977). Usually, reducing the soil water content provides good aeration. For example, it is recommended that seedlings be planted in a high, well-drained spot where the soil is warm. In southern

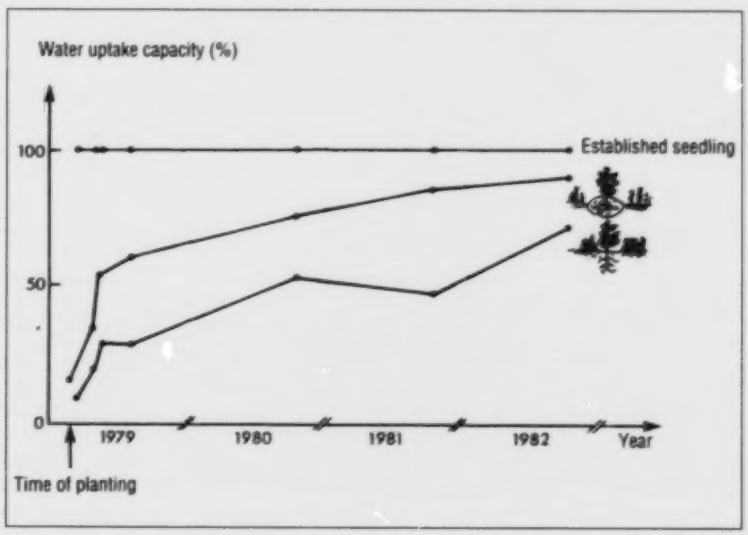


FIGURE 4. The water uptake capacity of Scots pine seedlings planted in a mineral mound (mound on mineral soil) and without site preparation. The water uptake capacity is compared in relation to established seedlings in the same area on a fresh, shrub type, sandy-silty moraine site. (after Örlander [1986a]).

After 4 years in the field, the water uptake capacity of planted seedlings has not matched the level of established seedlings. Mounding improved water uptake capacity from the first day following planting compared to planting without site preparation.

countries, or in local areas in Sweden where water deficits can occur, seedlings should be planted in the bottoms of furrows or depressions.

The site preparation methods used today are patch scarification, disc trenching, mounding and plowing. Schematic illustrations of the main methods discussed are show in Appendix 2. Since the choice of method can affect soil temperature, bulk density and drainage to varying degrees, different methods should be used on different types of sites.

Seedling affected by water stress (right) after planting. Seedling to the left has normal shoot development. Photo: Göran Örlander.

PRODUCTION FACTORS

- *Site preparation can affect several of the factors which limit seedlings' survival and growth. These factors are referred to as production factors. Above-ground factors which can be altered include incoming radiation, humidity and temperature; below-ground factors include water availability, oxygen content, soil temperature, nutrient availability and soil density.*

CHAPTER 2

2.1 Soil Temperature: Seedling Reaction

The function of seedling roots is influenced by soil temperature. Direct water and nutrient uptake, as well as root growth, is affected.

Optimum soil temperatures for root growth are about 30° C for Scots pine and 25° C for Norway spruce (Söderström 1976b).

At low soil temperatures, few lateral roots are produced and the root system is not as branched as at high temperatures (Russell 1977, cf. Söderström 1976b). Low soil temperatures may even hinder shoot growth (Figure 5). Optimal temperatures for shoot growth are between 20 and 30° C but there are large variations between species and probably within species. Southern species (provenances) generally have higher temperature requirements than northern ones (Russell 1977).

Some species demonstrate adaptation to low temperatures (cf. Söderström 1976). This means that seedlings reared under low temperatures manage better than seedlings reared under high temperatures when planted out to low temperatures.

Water uptake capacity has roughly the same optimal soil temperature as root and shoot growth (Figure 6). A reason for better water uptake at higher temperatures is the decrease in viscosity of water (Cooper 1973). Water uptake and seedling growth decrease at high temperatures. Temperatures around 50° C are fatal for root cells. For example, 49° C is the highest temperature at which jack pine can survive (Sims 1975). Damaging temperatures can occur at the soil surface at northern latitudes. It is difficult to differentiate between dam-

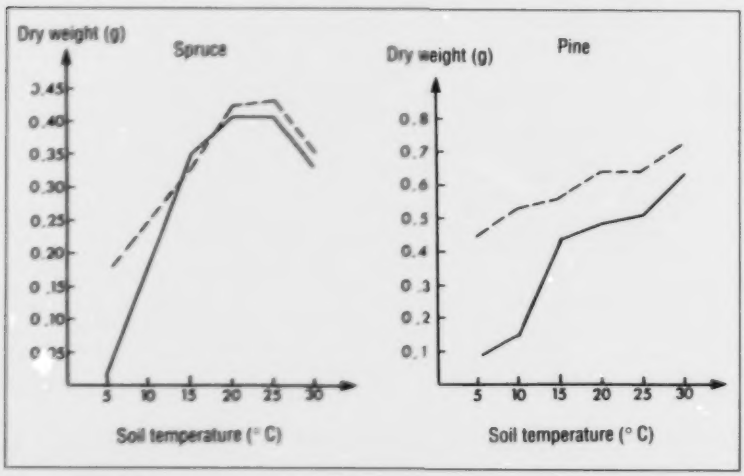


FIGURE 5. Root (——) and shoot (— —) growth 112 days (Norway spruce) and 120 days (Scots pine), respectively, after planting at different soil temperatures (after Söderström [1976b, 1979, respectively]). Optimal temperature for growth of spruce roots is 20-25° C, while pine roots grow better up to 30° C.

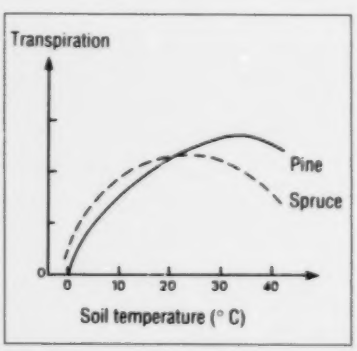


FIGURE 6. The effect of soil temperature on Scots pine and Norway spruce transpiration (after Örlander [1985]).

The figure shows that water uptake capacity of roots (expressed as water given off from needles) is greatest at 20-25° C for spruce and 30-35° C for pine.

age caused by heat and damage caused by desiccation since both occur concurrently.

Seedling nutrient uptake is inhibited by low soil temperatures (Figure 7). This is a consequence of low water uptake as well as reduced root respiration.

Soil temperature depends on the amount of energy that is absorbed or released, mainly in the form of short and long wave radiation. It is further influenced by the soil's heat capacity and thermal conductivity. Heat capacity refers to the soil's capacity to change temperature for a specific amount of heat input or loss; thermal conductivity refers to the soil's capacity to conduct heat. In late spring and summer when incoming radiation is high and nights are short, absorption is greater than re-radiation and the soil warms up. The opposite is true in autumn and winter. Both heat capacity and thermal conductivity vary with the soil's air and water content, as well as the amount of humus (Figure 8). Thermal conductivity is, for example, low in peat or humus and high in mineral soil.

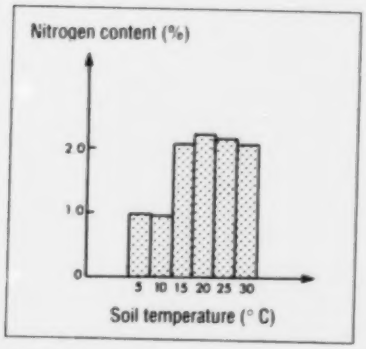


FIGURE 7. Nitrogen content in terminal needles of Scots pine 120 days after planting in soil with different temperatures (after Söderström [1979]).

The experiment shows that nitrogen uptake is limited at low temperatures, and hence there is low nitrogen content in the needles. Available nitrogen in the soil was not limiting.

Dry and moist soils have lower heat capacity than wet soils and warm up more rapidly. However, dry soils have a low thermal conductivity, so only the surface layer will be warm. Wet soils have a high heat capacity and high thermal conductivity which leads to cool surface temperatures. Energy is used to evaporate water from wet soils, which further decreases soil warming which makes wet soils cold. Wet soils will cool more slowly than dry soils during nights or late in the autumn. Consequently, under certain circumstances, wet soils can be slightly warmer than dry soils.

2.2 Soil Temperature: Effect of Site Preparation

The soil temperature under an undisturbed humus layer seldom reaches above 20° C in Fennoscandia. Soil temperatures are significantly lower in older stands. Removal of the humus layer increases soil temperatures (Figure 9).

Soil temperature is also influenced by aspect. Southern aspects warm up more. The north side of a plowed berm or terrace would therefore be warmer than the southern side (Söderström 1975, 1976a; Ritari and Lähde 1978). The temperature of a disc trench furrow or a patch can also vary considerably according to aspect (Figure 10).

Some very large increases in temperatures have been recorded in mounds and plowed berms (Söderström 1975, 1976a; Ritari and Lähde 1978).

Comparisons of soil temperature sums often show large differences between site preparation methods. These variations are greatest during the summer when solar radiation is high. Differences between a plowed berm and an untreated site can reach above 230 degree days (Figure 10). In Fennoscandia, this is equivalent to a corresponding shift in 4° of latitude or 200 m in elevation. The favourable effect of site preparation and soil temperature on

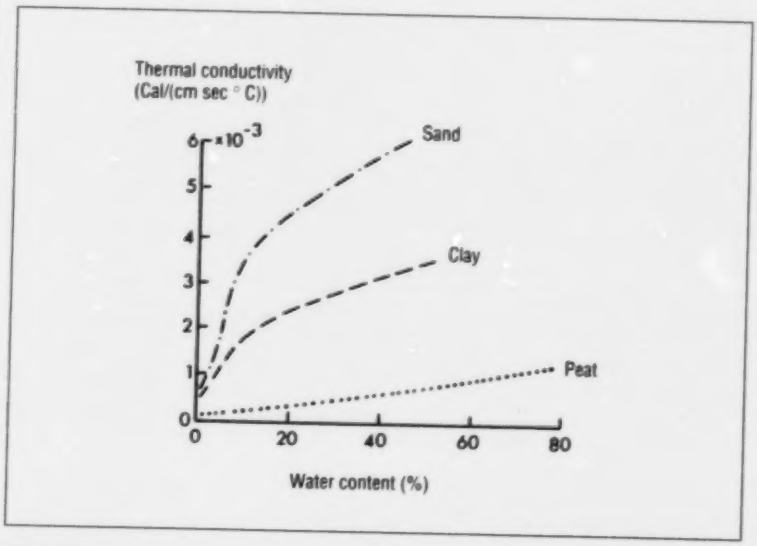


FIGURE 8. Thermal conductivity in different soil textures with different water contents (after Hillell [1982]).

Sand has a considerably higher thermal conductivity than peat. On warm sunny days, sand can reach temperatures favourable for root growth while peat temperatures are often lower.

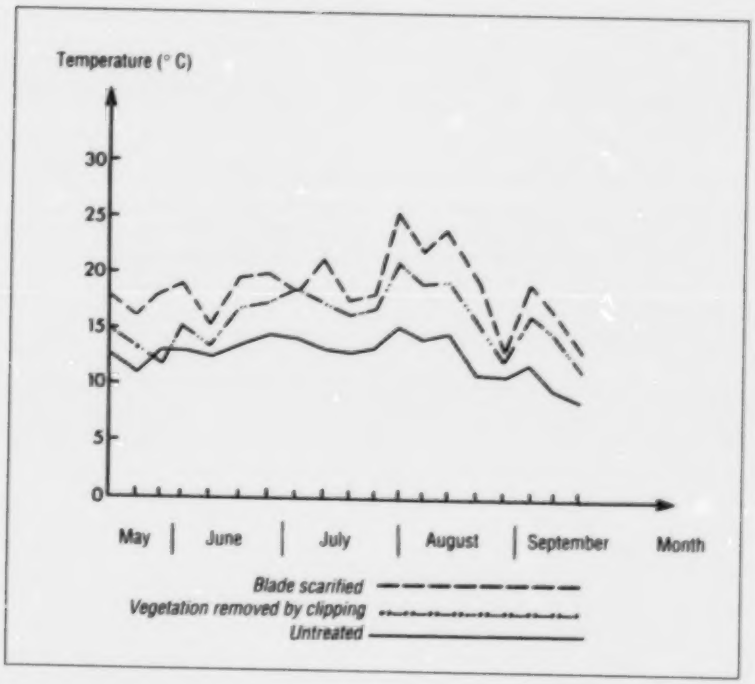


FIGURE 9. Soil temperature in untreated, blade-scarified and clipped microsites. Temperatures measured at 5 cm depth, in the afternoon on a densely vegetated site in Prince George (after Dobbs and McMinn [1977]).

The experiment shows that removal of the vegetation and exposure of mineral soil increases soil temperature and creates a favourable environment for seedling roots.

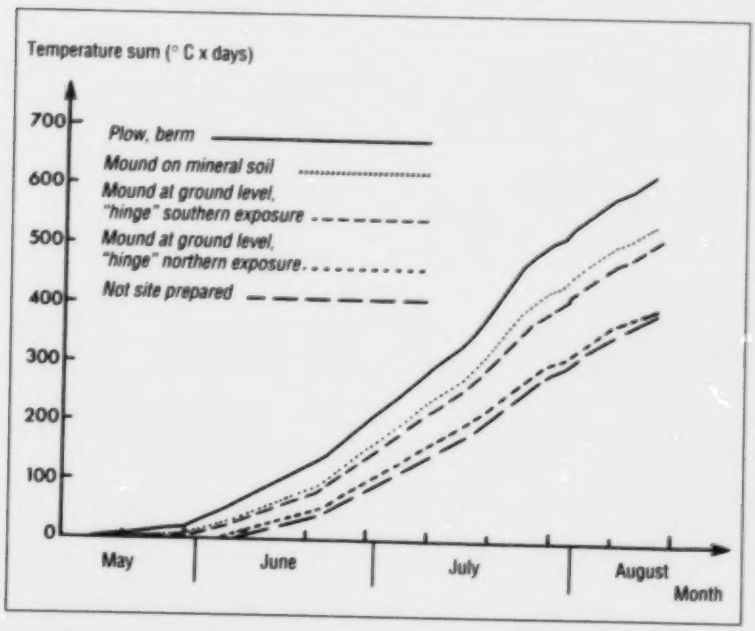


FIGURE 10. Soil temperature at a depth of 10 cm with different site preparation treatments at Vindeln (northeast Sweden), 1987. Temperature is expressed in temperature sums using a 5° C threshold (after Örlander [unpublished data]).

Soil temperature is strongly influenced by site preparation method. The figure also shows that the planting spot has great significance for the temperature around seedling roots. It can be important to choose planting spots with southern exposures, especially in cold climates.

seedling survival and growth has been clearly demonstrated in many studies (Mälkönen 1972; Dobbs and McMinn 1977; Ritari and Lähde 1978; Söderström 1979; Örlander 1987).

Soil temperature shows clear daily variation, with a temperature curve resembling a sine wave. The surface layer has the highest fluctuations, from the warmest day temperature to the coolest night temperature (Figure 11). The site preparation method that gives the highest day temperatures also results in the greatest differences between day and night temperatures (Figure 12). On cloudy days, when incoming radiation is low, soil temperature is relatively independent of site preparation method. In late autumn, temperatures in plowed berms and mounds are lower than in untreated or patch-scarified soil (Figure 12). Temperatures can drop to -10° C at a 10 cm depth. Frost penetration and the insulating capacity of humus may create difficult conditions for frost thawing under inverted plowed berms (Bärring 1965; Pohtila 1977; Kubin and Poikolainen 1982) (Figure 13).

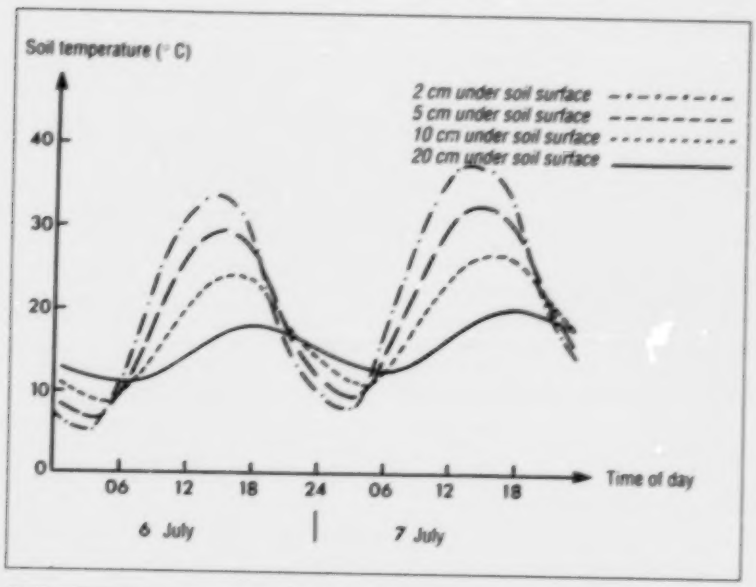


FIGURE 11. Soil temperatures at different depths of a mound on mineral soil. Weather was sunny and warm at Vindeln, 1983 (after Örlander [unpublished data]).

Favourable temperatures for pine roots were obtained at a depth of 10 cm in the mound. The significance of the large variation in surface temperatures between day and night has not been carefully studied.

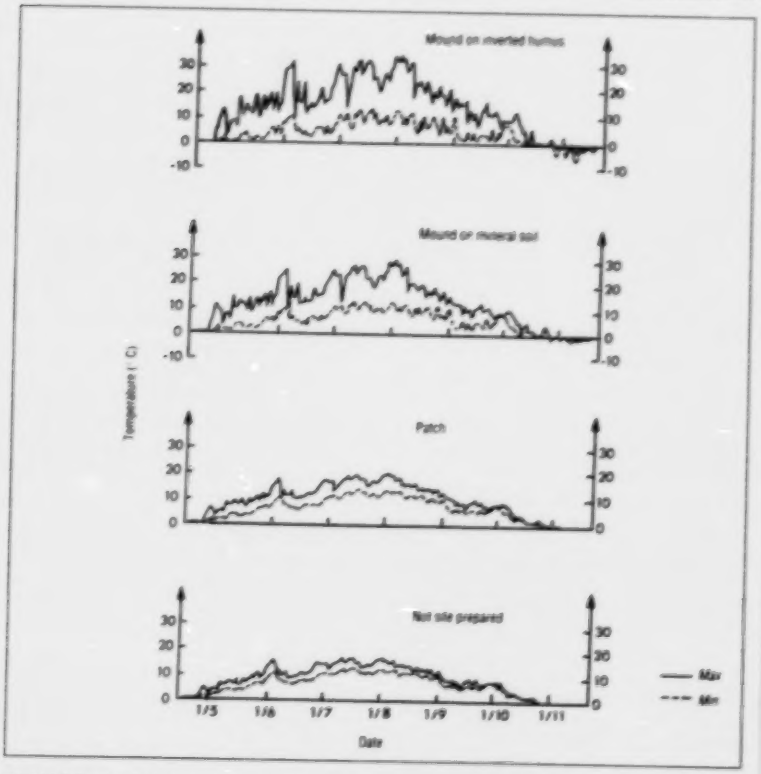


FIGURE 12. Daily maximum and minimum temperatures at a 10-cm depth with different site preparation treatments at Vindeln, 1982 (after Örlander [unpublished data]).

Mounds gave the highest temperatures during summer months and the most favourable temperatures for root growth. Mounds also had the lowest minimum temperatures. In autumn, minus temperatures were reached in the mounds, especially on inverted humus. It is possible that seedlings in mounds may be affected by damaging low temperatures.

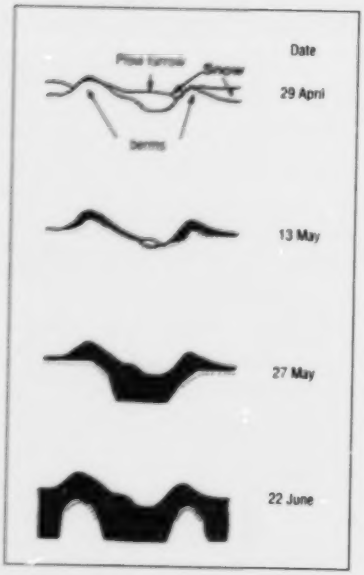


FIGURE 13. An example of frost thawing in a plowed profile in northern Finland (after Pohtila [1977]). Shading indicates thawed soil.

The berm acts as insulation, strongly delaying thawing.

2.3 Soil Density: Seedling Reaction

Swedish morainal soils typically have densities in the range of 1.3-1.6 g/cm^3 (Troedsson and Nykvist 1973). High soil densities such as these hinder root growth. A high density soil (compact) has low pore volume (porosity) and therefore lower air content and less readily available water than loose soil. There is also a risk of oxygen deficiency in compacted soils. Another disadvantage is that com-

pact soils warm more slowly than loose soils. They are also more mechanically resistant to root penetration, which results in reduced growth (Figure 14).

Ross and Malcolm (1982) found, for example, that pine roots could not penetrate the B horizon of a podsol soil when density was greater than 1.5 g/cm^3. A Soviet experiment (Sokolovskaya *et al.* 1977) indicated an optimal density for spruce roots of 1.2 g/cm^3 in an average fine-textured soil. Very fine-textured soils require more "loosening" than coarse soils to provide optimal conditions for root growth. The Soviet study indicated an optimal density of 1.1 g/cm^3 for soils containing clay.

Different tree species react differently in various soil densities. An American experiment, for example, showed that *Pinus contorta* had very good root penetration in a dense soil compared with *Picea sitchensis* (Minore *et al.* 1969).

The resistance to root penetration in compact soil is greater when the soil is dry than when it is wet (Russell 1977). On the other hand, growth potential in a wet soil may be reduced because of lower available oxygen.

2.4 Soil Density: Effect of Site Preparation

The soil's natural density is often higher than optimal for both seedling establishment and forest production. The increasing mechanization in forestry raises the risk for further compaction (a risk that is even greater and more serious in agriculture [e.g. Eriksson 1982]).

As mentioned above, a loosened soil is often favourable for seedling growth (Figures 14 and 15). Some loosening of the planting spot should be done at planting (cf. Sinko and Jakabffy 1972), although too much can dry out the soil and disturb plant water uptake by interfering with root/soil contact (Örlander 1984) (Figure 16). Loosening may affect the risk of frost heaving (see section on frost heaving). Mounding and plowing increase soil looseness, reducing soil density and increasing porosity (Mutka and Lähde 1977; Lähde 1978; Ritari and Lähde 1978; Lähde *et al.* 1981) (Figure 17).

Such soil loosening may last for many years. Loosening that occurs with disc trenching or patch scarification is also favourable for root growth but its duration may be short (Söderström 1976a).

On many site types where soil density is high or the soil profile is unfavourable, persistent low soil densities may be gained by plowing. In Germany and Scotland, for example, where hardpan soils occur, methods that totally cultivate the soil to a depth of 40-90 cm are used (ex. Hoctanner and Seitschek 1964;

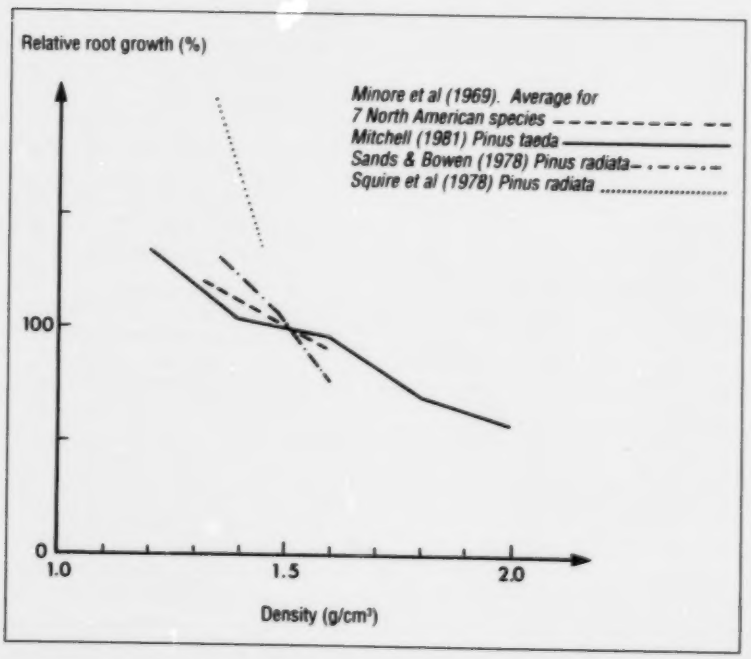


FIGURE 14. The relationship between root growth and soil density according to several experiments. The studies indicate that compaction negatively influences root growth and loosening of soil with normal densities (1.3-1.6 g/cm^3) has positive effects.

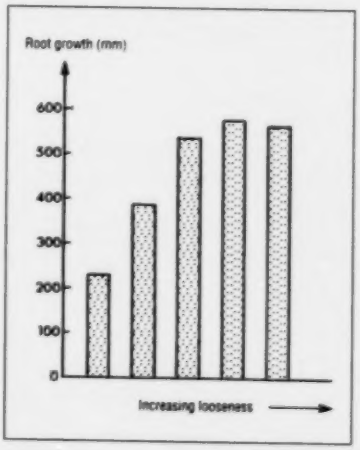


FIGURE 15. Root growth of recently planted Scots pine seedlings in relation to different soil looseness. The sandy site was disc-trenched at different speeds (after Bäcke [unpublished data]).

Loosening of the soil more than doubled root growth in this experiment.

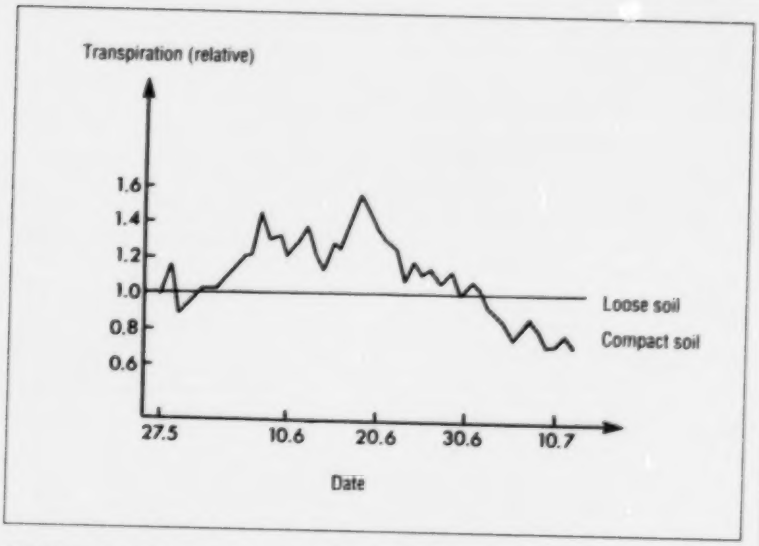


FIGURE 16. The figure shows a Finnish experiment where seedlings were planted in compact and loose soil (1.0 line). Transpiration of the seedlings planted in compact soil is shown in relation to that of seedlings planted in loosened soil. Seedlings in the compact soil had higher transpiration directly after planting, but the seedlings in loosened soil, through better root growth, recovered faster over time (after Smolander et al. [1981]).

This can be explained by the better initial availability of water in the compact soil. The root growth in the loosened soil was better and quickly improved the seedlings' water balance.

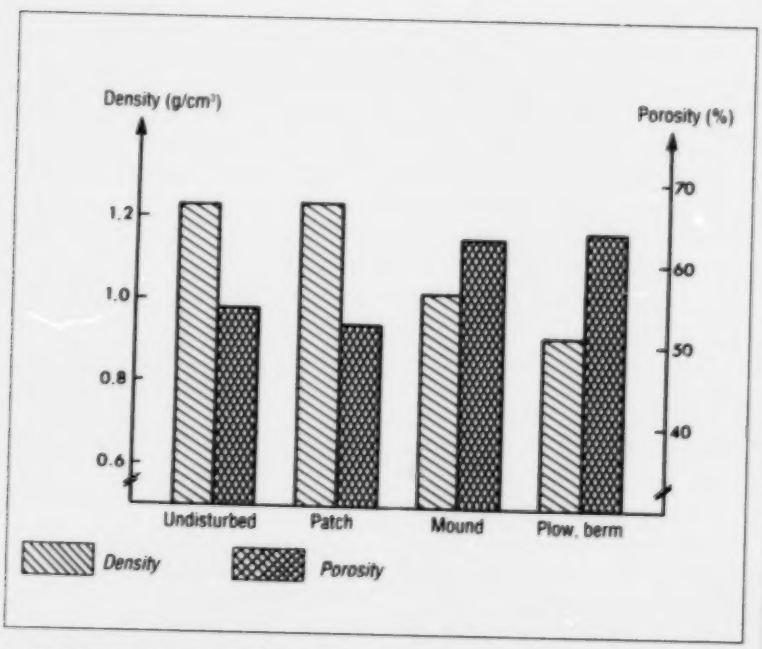


FIGURE 17. Density and porosity at 10-20 cm depth in soil treated with different methods (after Ritari and Lähde [1978]).

Mounding and plowing have created soil conditions that are favourable for root growth.

Kohh 1970; Hetch *et al.* 1981; Ross and Malcolm 1982) (Figure 18). Besides loosening the soil, plowing redistributes humus material to deeper depths, which promotes a deeper root system.

2.5 Relative Humidity: Seedling Reaction

Both air and soil moisture affect how much water is taken up and given off by a seedling. One can think of the flow of water through a plant as a flow from high to low water potential. Water potential is usually expressed in units of pressure such as the bar or pascal (Pa). In free water it is set at zero; in the soil, it is usually in the order of 0 to -3.0 MPa. Plant water potential must be lower (more negative) than that in the soil so that the plant can remove water from the soil. The temperature and relative humidity of the air determine the atmospheric evaporative demand. High relative humidity leads to low evaporative demand on the plant. This results in a low rate of transpiration and stomata can therefore stay open. Low relative humidity and high air temperature result in high evaporative demand on the plant. Usually the plant can not meet the demand and it regulates water loss by closing its stomata (Figure 19). This results in reduced photosynthesis since less CO_2 can enter the needles. Seedlings cannot completely stop water release, even if the stomata are closed. Norway spruce and Scots pine have, however, good stomata control functions and tolerate drought relatively well.

A recently planted seedling often has a poor capacity to take up water (Örlander 1984). These seedlings will therefore be stressed during periods with high temperatures and low relative humidity. These periods commonly occur during early- and mid-summer and can cause

high mortality, which is often mistakenly explained as being the result of soil water deficiency.

Relative humidity varies throughout the year. During early and mid-summer in Sweden, it is generally too low to provide maximum growth. Wind increases the water loss from seedlings. However, the effect on coniferous seedlings is relatively small and can often be disregarded.

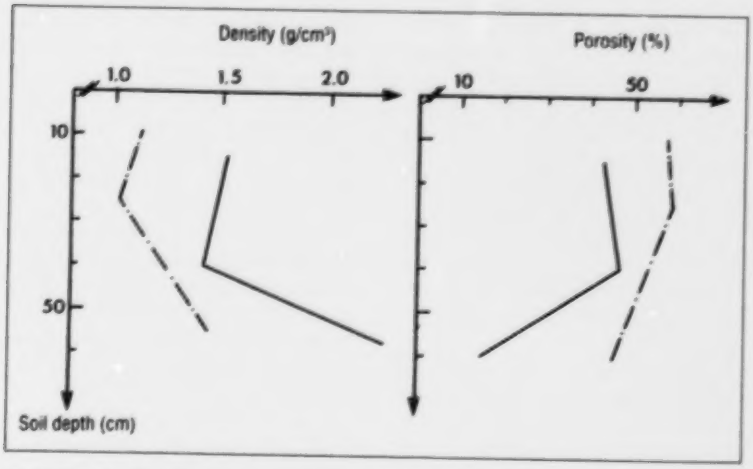


FIGURE 18. Density and porosity in a deep plowed (—·—) and untreated (——) soil. The example is from a Scottish compact, hardpan soil type (after Ross and Malcolm [1982]).

Deep plowing strongly loosened the soil, which is necessary for roots to grow in compact soil layers.

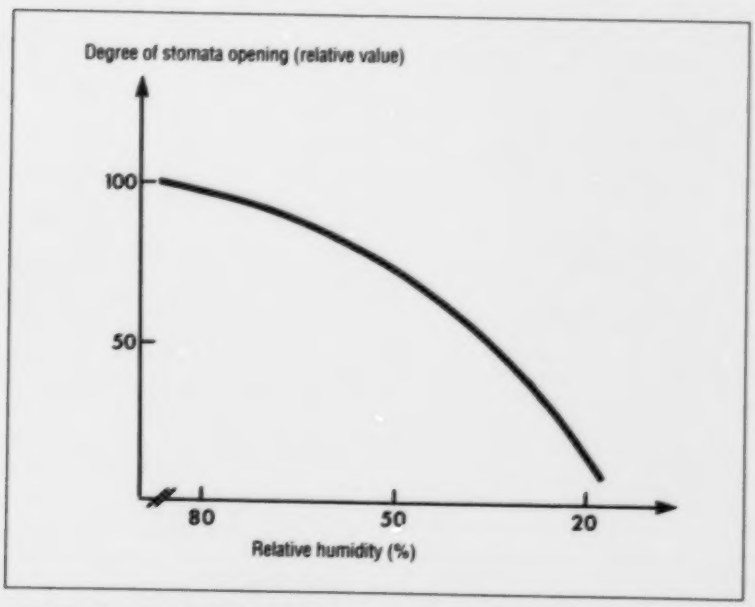


FIGURE 19. The influence of relative humidity on the degree of stomata opening for pine seedlings (after Jarvis [1980]).

Seedlings close stomata at low relative humidities to prevent desiccation.

2.6 Relative Humidity: Effect of Site Preparation

The potential to influence the humidity around seedlings is limited. Planting in scarified patches on older clearcuts with dense vegetation can have positive effects on relative humidity around seedlings (Lindman and Nordström 1964). Similar results can be obtained with "green slash planting" (planting immediately following logging) or planting under a dense, low overstory. The positive effects depend on protection from wind and sunlight, and subsequent reductions in needle (leaf) temperatures. These effects are not great for spruce and pine since needle temperatures are about the same as the air independent of incoming radiation (Örlander *et al.* 1989). Shading, on the other hand, can result in lower photosynthesis and subsequent reduced plant growth.

An attempt has been made to provide seedlings with plastic protection, the so-called "PUM" (Swedish acronym for "planting without site preparation") casings. These maintain a high relative humidity around the seedling. Positive effects on seedling development have been shown with PUM.

In eastern Sweden, where low humidity and dry periods can occur during early and mid-summer, it may be preferable to delay planting until autumn.

2.7 Soil Moisture: Seedling Reaction

A fresh (subhygric to mesic) clearcut site generally has adequate soil moisture. Harvesting removes the transpiring forest layer, and there is not sufficient vegetation to deplete water reserves. For example, Söderström (1970) found high soil moisture in the parts of Sweden with the lowest relative humidity, even

during dry years. On fresh sites, a lack of soil moisture is not a problem for seedling survival.

Water is bound in the spaces between soil particles, in the pores. The smaller the pores, the more tightly bound the water. The binding of water in the soil is expressed in units of pressure (water potential). In older units, this is the logarithm scale in centimetres of the height of a water column, the pF value. Concepts commonly found in the literature are field capacity (water potential when free water has drained out of the profile) and wilting point. The latter term refers to the water potential where the plant can no longer take up water. This concept is a little misleading since the wilting point differs according to type of plant, physiological state, weather conditions, etc. Wilting point is often set at -15 bar = -1.5 MPa = pF value 4.2. The relationship between water volume and binding pressure for different soils is called the pF or soil retention curve (Figure 20).

The rate of flow of water in the soil varies with both soil type and the soil water content. The flow of water in a saturated soil, that is, with free water, is high in coarse-textured soils and relatively slow in fine-textured ones. When the soil dries, the hydraulic conductivity quickly decreases, especially in coarse-textured soils (Figure 21).

The flow of water in the humus layer or peat depends on the degree of decomposition. A highly humified peat conducts water poorly compared with a low humified peat. This is significant for the choice of sites suitable for ditching and the spacing required to obtain adequate drainage.

Water moves from areas of high water potential to those of low water potential. If there are temperature differences in the soil and soil moisture is constant, then water moves toward points of lower temperature. At night, water moves up in the profile toward the cool surface. Temperature-dependent water transport is generally small in comparison with that occurring from moisture differences. However, it is important in the formation of needle ice and frost heaving.

In dry sand the hydraulic conductivity is extremely low. The surficial sand layer (or other coarse substrate) breaks the water transport from deeper layers. During dry weather, this "capillary breaking" layer impairs evaporation from the soil and favourably affects available plant water.

Soil water deficits have a negative effect on seedling water uptake, though this varies with different situations. An established seedling growing in relatively fine-textured soil tolerates drought fairly well. A recently planted seedling (bare-root or container), grown in a coarse substrate (such as peat), will be sensitive to drying (Örlander and Due 1986b) (Figure 22).

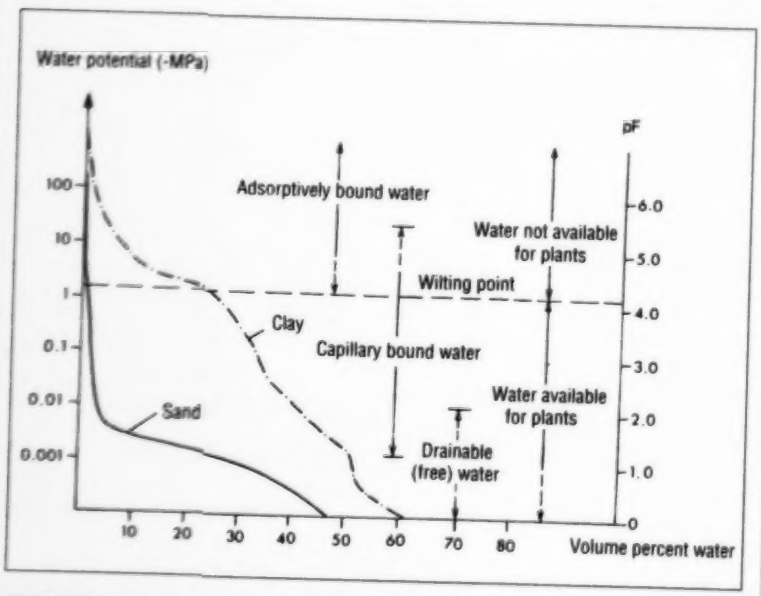


FIGURE 20. A pF curve demonstrating the relationship between percent moisture by volume and water potential (after Anderson [1973]).

A fine-textured soil binds water more strongly than a coarse-textured one.

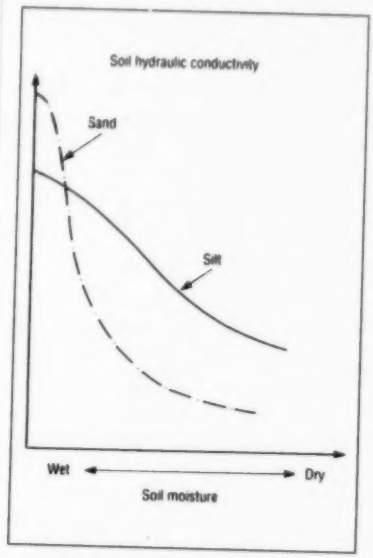


FIGURE 21. Soil hydraulic conductivities for different soil moisture levels (water potential) (after Hillel [1982]).

At high moisture levels, coarse-textured soils conduct water more easily than fine-textured soils. The reverse is true at low moisture levels.

2.8 Soil Moisture: Effect of Site Preparation

Even though soil moisture deficits can cause poor seedling water balance, the most common causes of poor water uptake in recently planted seedlings are poorly functioning root systems, low soil temperatures, and oxygen deficits in the soil.

Site preparation offers great possibilities to influence the moisture conditions around seedling roots. The aim of the treatment is to provide the planting spot with relatively high, secure moisture availability, without risk of oxygen deficiency.

Removal of competing herbs or grass ensures more secure availability of moisture (Bärring 1965; Söderström 1979). However, on moss or lichen sites, removal of the humus could lead to drying out, especially at the soil surface (Söderström 1979).

Often the soil moisture in scarified patches is so high that there is a risk of oxygen deficiency (Söderström 1974a). This is pronounced when the patch or disced trench results in a deep depression or furrow. Piling mineral soil in a mound creates good drainage. If the mound is over mineral soil, then water availability is relatively assured, even during dry years (Figure 23). On mounds or berms piled over inverted humus, the risk for desiccation is large (Söderström 1976a; Pohtila 1977). The reason is that the inverted humus appears to slow down transport of water from deeper layers, due to the humus having a much lower unsaturated hydraulic conductivity than mineral soil. Changes in soil moisture and the subsequent risk of desiccation are greatest in the surface layer. Soil moisture is high under the humus layer (Figure 23). It is important that the piled humus be placed against the ground. There should not be too much slash between the inverted humus and

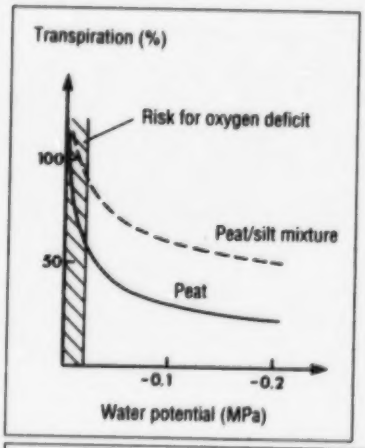


FIGURE 22. The relationship between soil water and seedling water uptake. Seedlings were grown in peat and a peat/silt mixture (after Örlander [1985]).

A more favourable water uptake can be obtained using an admixture of silt with peat compared with pure peat.

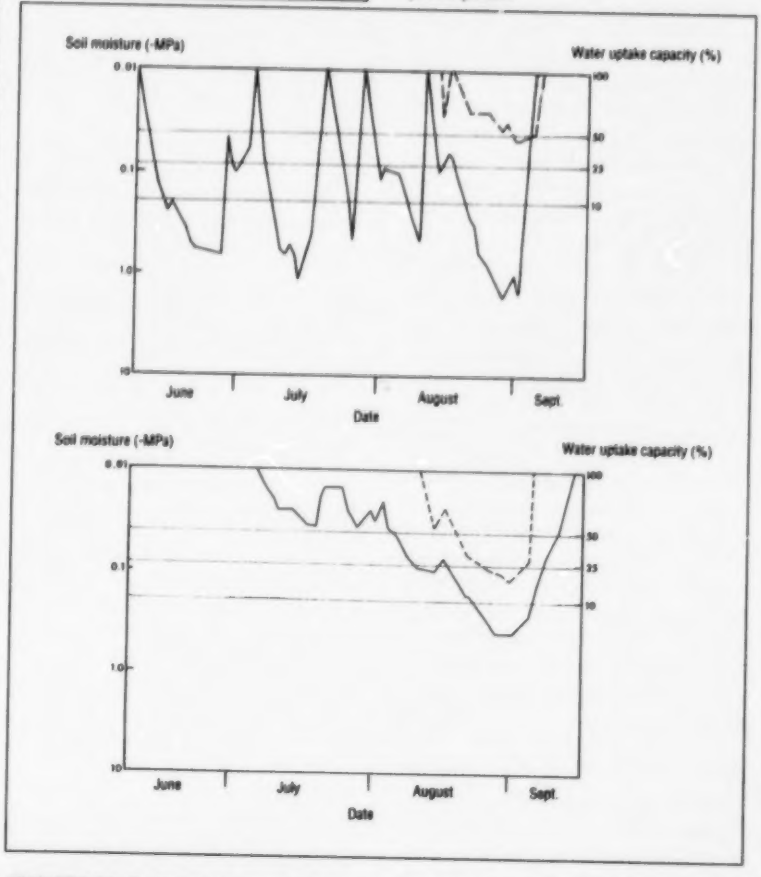


FIGURE 23. Soil moisture at 10 (——) and 20 (— —) cm depth in mound (15 L) on mineral soil (lower graph) and on inverted humus (upper graph). Measured at Vindeln during the dry summer of 1983. The water uptake capacity of recently planted Scots pine seedlings is shown for comparison (after Örlander and Due [1986a] and Örlander [1984], respectively).

The experiment shows that during dry summers, moisture in mounds on inverted humus is low and seedlings planted at normal depths can have trouble surviving. These problems do not usually occur in seedlings planted on mounds on mineral soil. At depths of 20 cm there is full moisture for most of the summer.

the ground, and the mounded material should have enough weight to press the humus together.

The risk of drying out mounds on inverted humus decreases with time, since the humus breaks down and capillary contact is restored. The risk of drying is also related to the ground water level, soil moisture, and soil type. On fine-textured soils, the unsaturated hydraulic conductivity is relatively high and the surface layers conduct water even during dry periods. Consequently there is greater risk of desiccation in inverted humus mounds on fine-textured soils than on coarse-textured soils. Such soil will be dry over the humus (Figure 24).

The risk for drought following planting depends on the amount of precipitation in relationship to evaporation. Figure 25 illustrates the climatic moisture deficit (precipitation minus potential evaporation) during spring. Evaporation is greater than precipitation for all of eastern Sweden, and this can create drought problems with planting. The problem is especially acute for planting spots sensitive to desiccation, such as inverted humus mounds or plowed berms. The map shows 30-year averages, though the variation between years is high. This variation can be illustrated in the form of a "p^{05}-value", which represents the precipitation that falls below that amount 5% of the years (Figure 26). The drought risk is highest during these years, which would occur 1 year in 20.

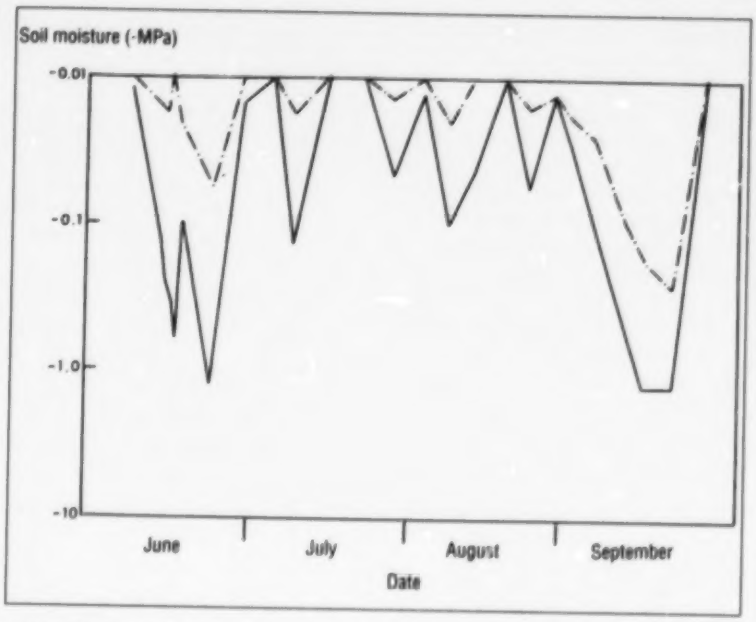


FIGURE 24. Soil moisture at 10 cm depth in mounds (15 L) consisting of sandy moraine (—·—) and silt (———) on inverted humus. Mounds were placed on the same site as Fig. 23 in 1981 (after Örlander [unpublished data]).

Mounds of fine-textured soils dry out faster than those of coarse-textured material because of the high hydraulic conductivity of the surface layer. It follows that seedlings may have trouble surviving during periods of drought in fine-textured mounds over inverted humus with interrupted capillary flow.

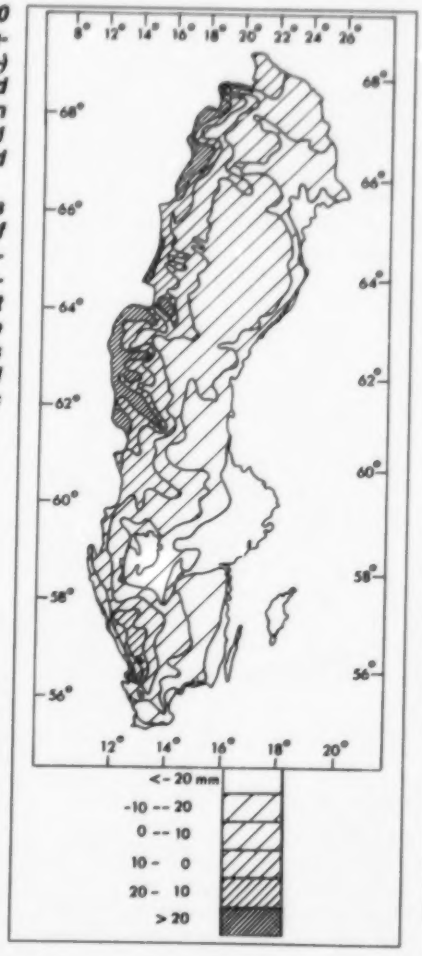


FIGURE 25. The climatic moisture surplus or deficit (precipitation - potential evaporation) in millimetres during the period 30 to 60 days after commencement of the growing season(after Eriksson [1986]).

In eastern Sweden there is a deficit during early summer, which creates problems in some years with planting.

2.9 Gas Exchange in the Soil: Seedling Reaction

Gas exchange in the soil is necessary to supply oxygen which is required for root growth (Figure 27). Seedlings can be damaged by poor gas exchange

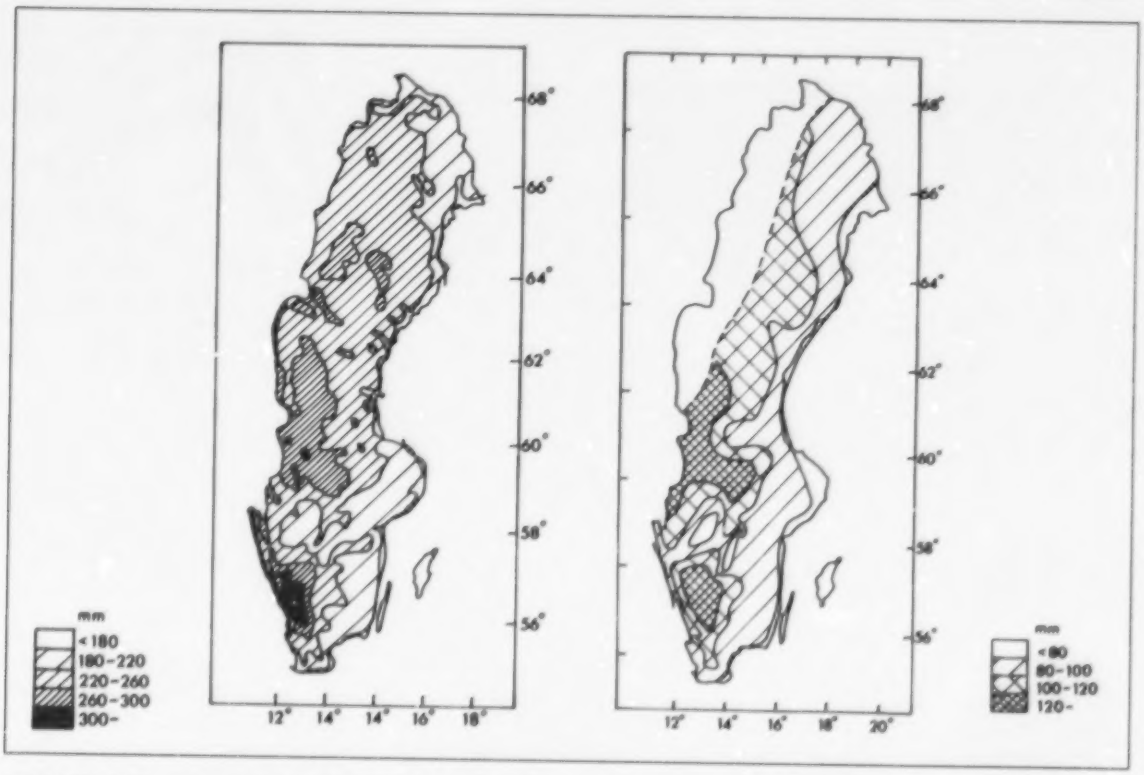


FIGURE 26. The map on the left shows the average summer (June-August) precipitation and the map on the right shows precipitation during the driest years. Precipitation will be lower than that shown on the right for 5 out of 100 years (after Eriksson [1986]).

The variation in precipitation between years is relatively large, which suggests that a site preparation method that yields good results one year may give poor results the next year.

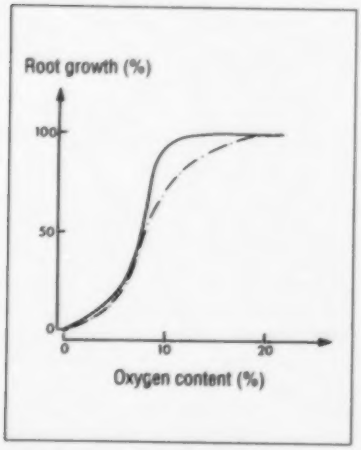


FIGURE 27. Root growth with different oxygen contents for jack pine (——) and Norway spruce (— · —) (after Leyton and Rosseau [1958]).

Roots need oxygen to survive and grow.

in the soil, partly because of oxygen deficiencies and partly because of toxic gases which can form from anaerobic conditions. Some examples of toxic substances are different organic acids, ethylene, carbon dioxide (in high concentrations), and hydrogen sulfide (Russell 1977).

Oxygen deficiencies most often occur as a result of saturation of soil pores. Gas exchange generally takes place in the air-filled pores of the soil. Oxygen diffuses 10000 times faster in air-filled pores than in water-filled pores (Russell 1977). Oxygen can also be transported in the soil profile by oxygen-rich ground water (e.g., in long slopes or along streamsides).

Porosity and water content in the soil vary with soil density and texture (Figure 28). This means that the air content in fine-textured soils is small, especially in silty clay. As a rule, a minimum air volume of 10% is required to avoid oxygen deficiency (Lähde 1975; Ritari and Lähde 1978). The consumption of oxygen in the soil depends partly on plants' respiration and partly on the decomposition of organic material. When soils are cold, the consumption of oxygen is low and the risk of oxygen deficiency is small. Oxygen deficiencies occur when water levels are high during the growing season. Negative effects from lack of oxygen can occur even if the period of high water is as short as 1 day (Russell 1977).

Under oxygen-poor condi-

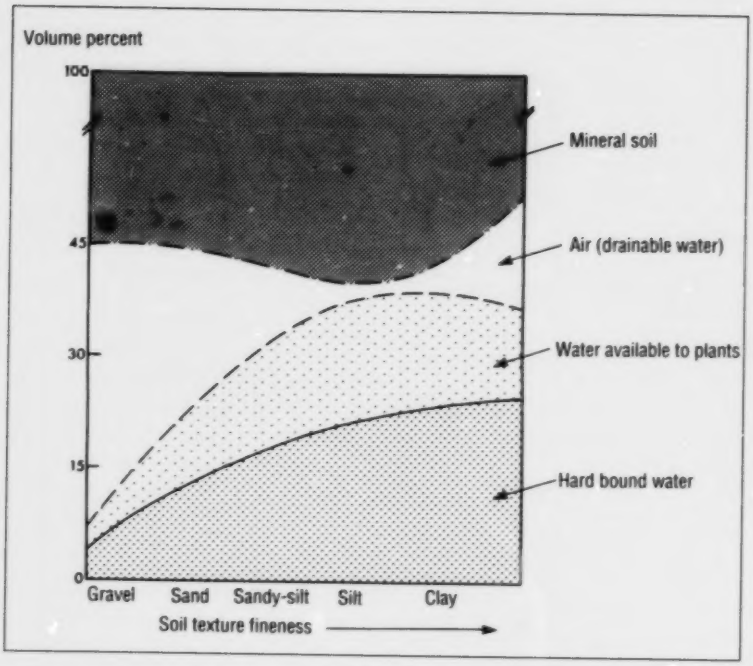


FIGURE 28. The distribution of mineral soil particles, air and water in soil of different textures.

Fine-textured soils have little space for air. Oxygen deficiencies therefore most commonly occur in these soils.

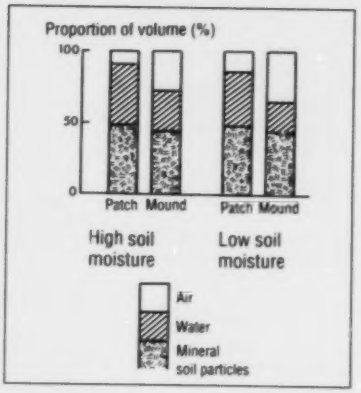


FIGURE 29. The distribution of mineral soil particles, water and air for soil with different site preparation treatments. Measurements were carried out in a summer with partly moist and dry conditions. The limit for oxygen deficiency is about 10% air in the soil (after Ritari and Lähde [1978]).

Pore volume and proportion of air in the soil is greater in mounds than in patches, so oxygen deficiencies will not likely occur in mounds.

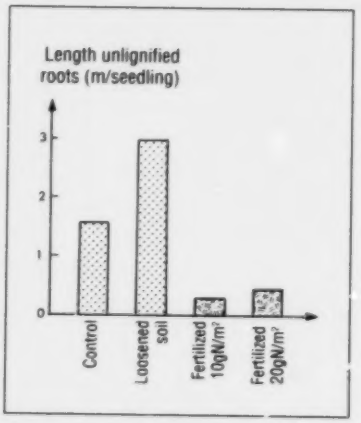


FIGURE 30. The effect of loosening and nitrogen fertilization on root growth. Planting carried out after patch scarification. Fertilizer was evenly distributed over the patch. Average values for Scots pine and Norway spruce in Fransbo and Flakaträsk (after Söderström [1976a]).

Root growth was better in unfertilized parcels than fertilized ones (one application). The best root growth was found in loosened, unfertilized parcels.

tions, significant quantities of nitrogen can be lost from the soil through denitrification and leaching (Russell 1977).

2.10 Gas Exchange in the Soil: Effect of Site Preparation

Oxygen deficiencies seldom occur in the humus layer of forest soils (cf. Romell 1922). On fresh sites with moraine or fine-textured sediment soils, oxygen deficiencies often occur in scarified patches or disc-trenched furrows (Söderström 1974b). To avoid this situation, one should prepare the site to create a drained planting spot. Mounding not only creates a drained planting spot, but it also loosens the soil around the roots, promoting gas exchange. The proportion of air-filled pores is significantly lower in a scarified patch than in a mound (Figure 29). During periods of high moisture, the air volume in scarified patches may be less than the minimum value required for good oxygen availability. To ensure long-term availability of oxygen, the loosening of the soil should be durable, unlike that in a scarified patch or disced trench which is often short term. As a rule, mixing of humus and mineral soil ensures good, lasting soil loosening and long-term oxygen availability.

2.11 Soil Nutrients: Seedling Reaction

Nutrient availability in the soil is naturally important for seedling growth. Yet, direct effects of nitrogen fertilization can result in poorer survival and growth, especially root growth (Figure 30) (Mälkönen 1972; Söderström 1976a).

The reason for this is that

growth in recently planted seedlings is normally limited by water uptake (Örlander 1984). High concentrations of fertilizer can damage the roots. Besides, fertilizing favours shoot growth over root growth (Örlander 1986b), which can impair the seedling's water status. However, fertilization with phosphorous and potassium may be necessary for good establishment when planting on peatlands (Bergman 1980; Kanuisto and Päivinen 1985).

Fertilization with slow release phosphorous at the time of planting on mineral soil has usually given a weak positive response or no effect (Mutka and Lähde 1977; Huuri 1980). On the other hand, some experiments have shown positive results with fertilization. In an experiment where seedlings were supplied with low concentrations of complete fertilizer by drip irrigation, seedlings (especially Norway spruce) responded very favourably to fertilization (Örlander 1986b) (Figure 31). Obviously, seedlings can be stimulated by fertilization in low concentrations if there is a good water supply. An established seedling responds favourably to increased nutrient availability.

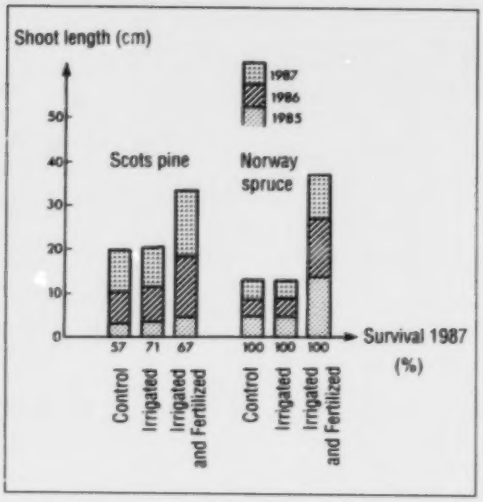


FIGURE 31. Fertilization and irrigation experiment in Vindeln. Low concentration (full) fertilizer was supplied by drip irrigation to recently planted seedlings (after Örlander [unpublished data]; cf. Örlander [1986b]).

Both Scots pine and Norway spruce had increased shoot growth with irrigation with low concentrations of fertilizer. Irrigation alone had no effect on growth.

2.12 Soil Nutrients: Effect of Site Preparation

In the years immediately following final harvest, nutrient availability is high, vegetation is present in a modest amount, and slash is decomposing. Mixing humus material and mineral soil, such as in plowed berms or mounds, produces an increased rate of mineralization ("compost effect"); (Lundmark 1988) (Figure 32). Berms have increased microbiological activity due to the favourable temperature and moisture conditions and access to humus material (Voss-Lagerlund 1976; Palmgren 1984).

It often takes a few years after

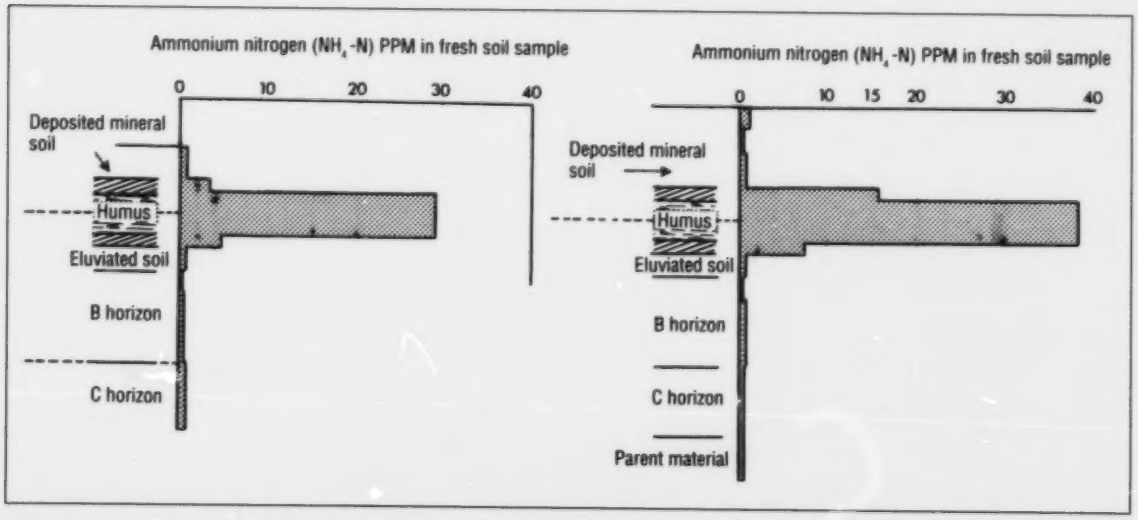


FIGURE 32. Mineralized ammonium nitrogen in fresh soil samples at different levels of plowed (right) and inverted humus mound (left) profiles (after Lundmark [1988]).

Mineralized nitrogen can be assimilated by seedling roots growing in the humus layer.

site preparation before benefits of the compost effect are realized. Studies show that mineralization of nitrogen, potassium and phosphorous is increased for at least 3 years following site preparation (Mälkönen 1986; Rosén and Lundmark-Thelin 1986) (Figure 33). The duration of the effect depends on climate and soil conditions. Studies in northern Finland (Tikkanen 1987) indicated that compost effects decline roughly 10-15 years following plowing. The effect of site preparation method on mineralization of nutrients naturally depends on how large an area of soil is disturbed. This has been studied by Lundmark (1988) and is further discussed in Chapter 8 on long-term effects.

The age of a clearcut has a large effect on the nutrient regime. As a clearcut ages, nutrients are more tightly bound in the soil and competing vegetation. "Harsh" site preparation is more greatly needed for regenerating an older clearcut than a recently cut site.

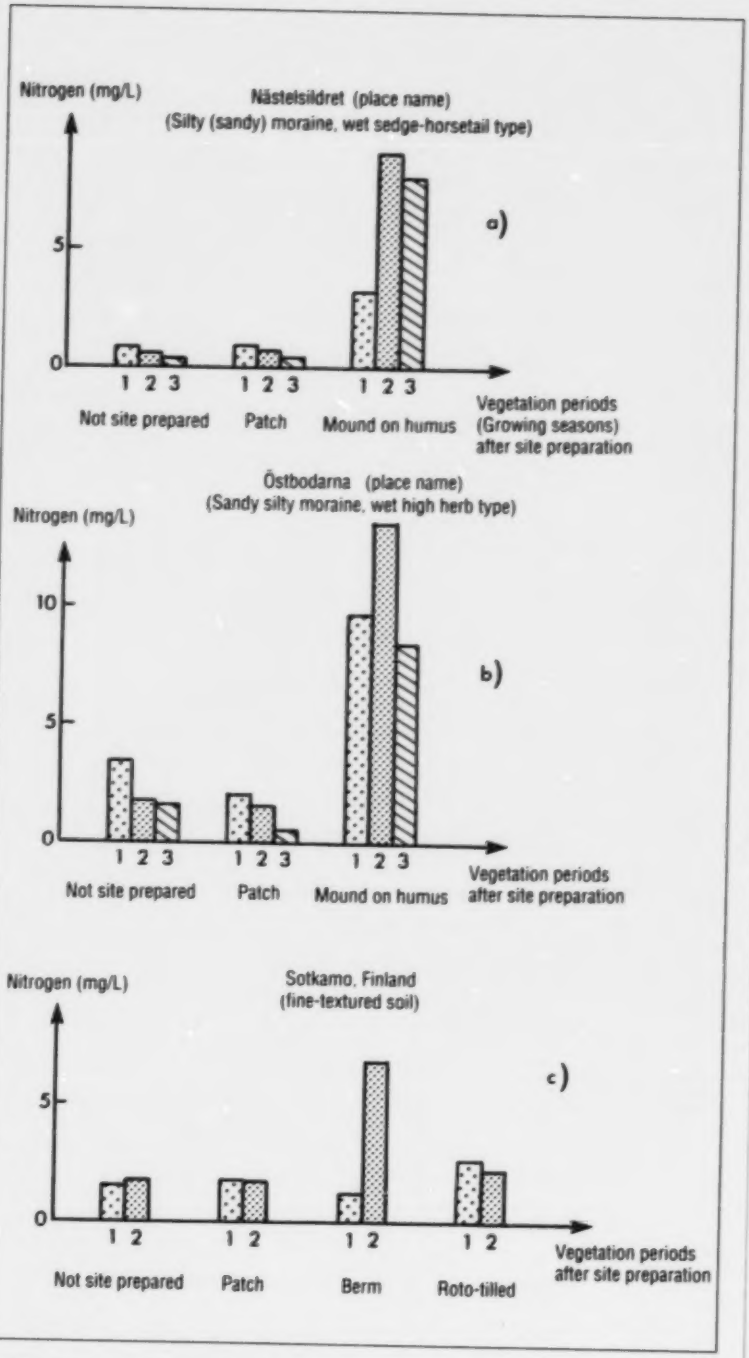


FIGURE 33. The concentration of nitrogen in soil water with different site preparations methods, 1-3 years following treatment. Samples were taken at depths of 15 and 20 cm (Figures A-B and C, respectively) (after Lundmark-Thelin [pers. comm.] Figures A and B; Mälkönen [1986] Figure C).

Nutrient mineralization is greatest in plowed berms covered with mineral soil. Mineralization is greatest a few years following site preparation.

MORTALITY CAUSES

CHAPTER 3

- *Site preparation can alleviate the effects of different damaging agents, thus improving seedling survival. Damage from frost heaving can be reduced by deep planting in inverted humus berms. Frost damage can be reduced with mounding or plowing. Pine weevil damage, a serious problem especially in southern Sweden, can be significantly reduced after mounding.*
- *Surrounding vegetation can impede seedling growth by causing competition and, in some cases, allelopathy. The negative effects of surrounding vegetation can be diminished with some forms of site preparation.*

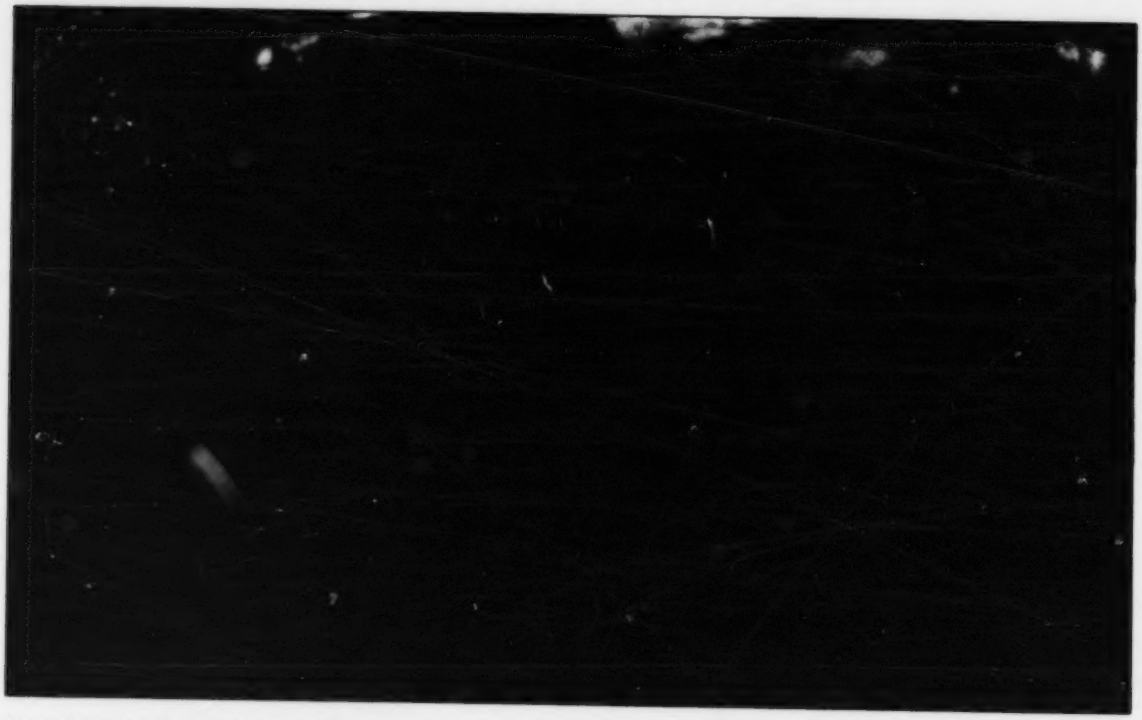
3.1 Frost Heaving

The problems of frost heaving and its subsequent effects on seedling survival hardly need any introduction to those involved in forestry. The phenomenon was described in the 1860's. (von Mohl 1860; Sachs 1860).

Frost heaving depends on the formation of ice layers (strips) in the soil profile when moisture availability is high. Water is conducted from below by capillary rise. It then freezes and the ice layers increase.

The risk for frost heaving is greatest when soil temperatures are 0° C or just below. If freezing takes place quickly, no ice layers develops. Ice crystals can form near the soil surface in wet soils that are covered with thin humus layers.

A prerequisite for frost heaving is that water is conducted from below to the ice front. The most important factors determining a soil type's tendency to frost heave are particle size, pore volume, and pore size. Wet soils with good hydraulic conductivity – such as sandy-silty mo-



Frost heaving is a problem on fine-textured soils. Photo: France Gaulet.

raine, fine sandy-silt, and silt – are especially susceptible to frost heaving. Even coarser textured soils may frost heave depending on the circumstances of the freezing cycle.

Frost heaving occurs mainly in the upper soil layers where temperatures fluctuate around 0° C (Figure 34). The risk for frost heaving in mounds increases when temperature fluctuations are large and there are repeated freeze-thaw cycles. (Figure 35).

Shading from ground vegetation or a shelter overstory can reduce the risk of frost heaving (Graber 1971). Because frost heaving mostly affects small seedlings, germinants, or recently planted seedlings (cf.Heidman 1976; Hagner and de Jong 1982a), susceptible sites should be planted with large stock during the spring so that roots can be firmly established during the growing season.

Heidman and Troud (1975) found that frost heaving increased with increasing soil density. However, in other cases frost heaving was reported to be worse in loosened soil than in more compact soil (cf. Wibeck 1920) (Figure 36).

Many factors complicate the process. Sometimes frost heaving can be worse in patches or disc-trenched furrows than in mounds (Figure 36). It is often less in inverted humus mounds or plowed berms since soil moisture is relatively low and there is poor capillary contact with deeper layers. The thickness of mineral soil capping is especially significant. If seedlings are planted through the inverted humus layer frost heaving should be reduced. Another method to reduce frost heaving is to plant deeply (Figure 36). This diminishes conditions for frost heaving and anchors the seedling firmly.

Covering the soil or not preparing the site can also lower the risk of frost heaving since the temperature fluctuations around 0° C are reduced.

The risk of frost heaving in an illuviated B horizon soil is greater than in eluviated soils

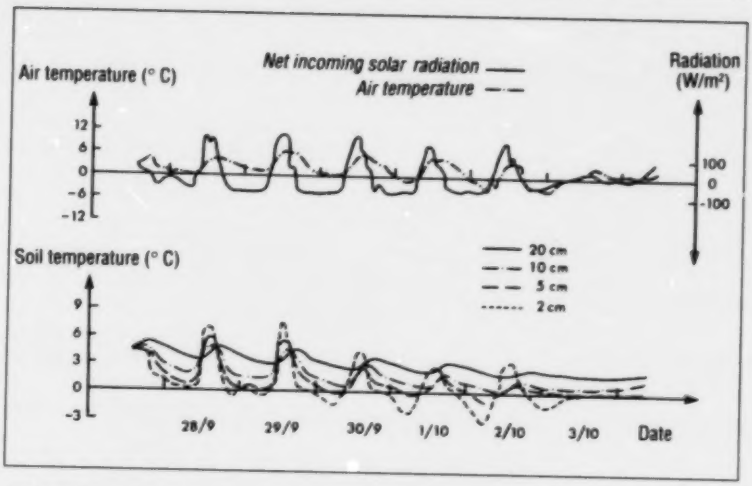


FIGURE 34. Air temperature, net incoming solar radiation, and soil temperature at different depths in a mound on mineral soil at Vindeln, 1983 (after Örlander [unpublished data]).

Variations in temperature are greatest in the upper soil layers. Repeated freeze-thawing leads to increased risk for frost heaving.

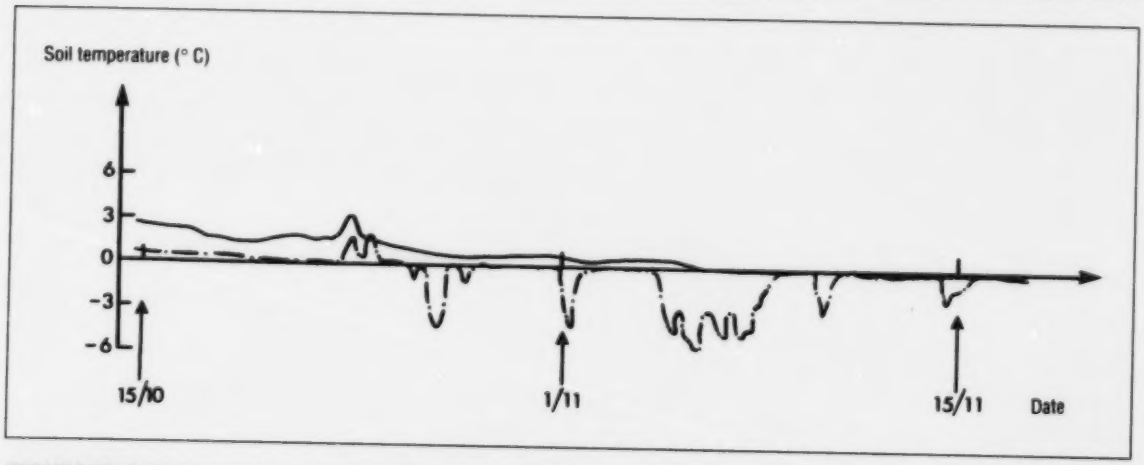


FIGURE 35. Soil temperatures at 10 cm depth in a patch (———) and an inverted humus mound (—·—) at Vindeln, 1982 (after Örlander [unpublished data]).

Soil temperature variations are high in a mound. This can lead to frost heaving with high soil moisture.

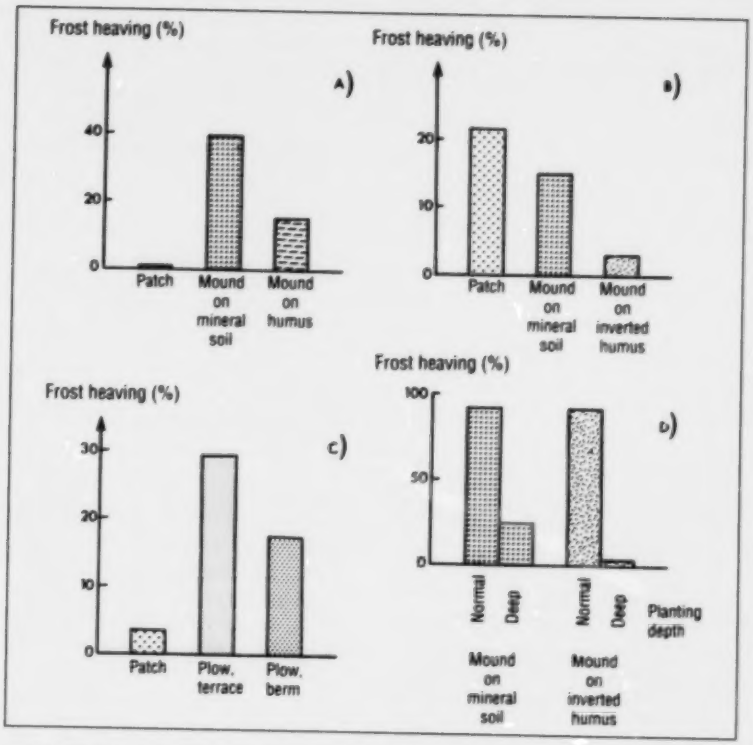


FIGURE 36. Examples of frost heaving frequency in a number of site preparation experiments. A) Sandy-silty moraine, bareroot Norway spruce, Orrefors (southcentral Sweden) (after Söderström et al. [1978]. B) Sandy-silty moraine, container Scots pine and lodgepole pine, Bräcke (northern Sweden) (after Bäcke [unpublished data]). C) Fine-textured moraine, northern Finland (after Pohtila [1977]). D) Medium (sandy) silt, container Scots pine, Vindeln (after Bäckström [unpublished data]).

The lowest frequency of frost heaving seems to occur in inverted humus mounds, especially with deep planting.

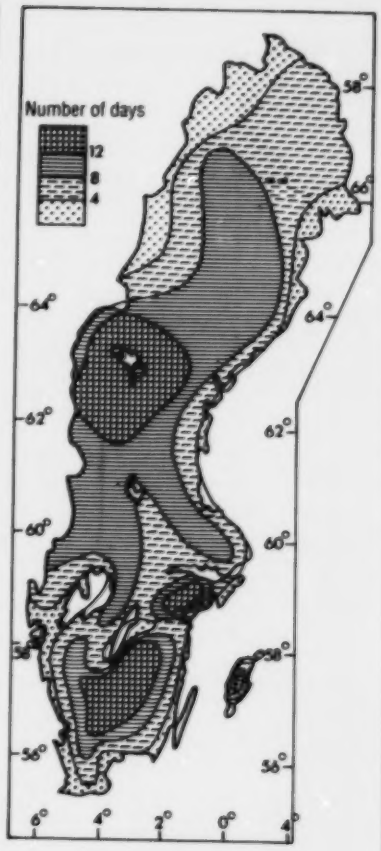


FIGURE 37. The number of days with frost from the start of the growing season to June 30.

Frost frequency is highest in the central southern Sweden and the central northwest.

(Hagner and de Jong 1982a). The reason might be that eluviated soils are more water repellent.

3.2 Frost

3.2.1 Seedling reaction

Forest regeneration may be affected by frost problems on flat sites such as peatlands in low lying terrain or pine heaths. Frost problems are greatest in central southern Sweden and in the central northwest (Figure 37).

Damage to flushing shoots can start between –3° C and –8° C. However, it is not enough simply to discuss the lowest temperatures that seedlings can tolerate. Frost hardiness, rate of freezing and thawing, and the duration of the lowest temperatures reached all play significant roles in the extent of frost damage (Sakai and Larcher 1987). Furthermore, Lundmark (1985) has shown that the amount of sunlight received the day following the frost has great significance on the extent of frost damage. Low temperatures damage the photosynthetic mechanism of seedlings. If this is followed by exposure to intense sunlight, the seedling's chlorophyll can be damaged (Strand and Lundmark 1987). This is later manifested by yellowing seedlings and mortality. Low temperatures that do not kill seedlings can drastically reduce photosynthesis (Figure 38).

During the night, the layer close to the ground cools off since outgoing longwave radiation exceeds incoming radiation. Consequently the air closest to the ground is the coldest (Figure 39). This is pronounced on wind-still nights. The degree of cooling varies with the soil's heat capacity and thermal conductance. In a wet soil without a humus cover, there is high

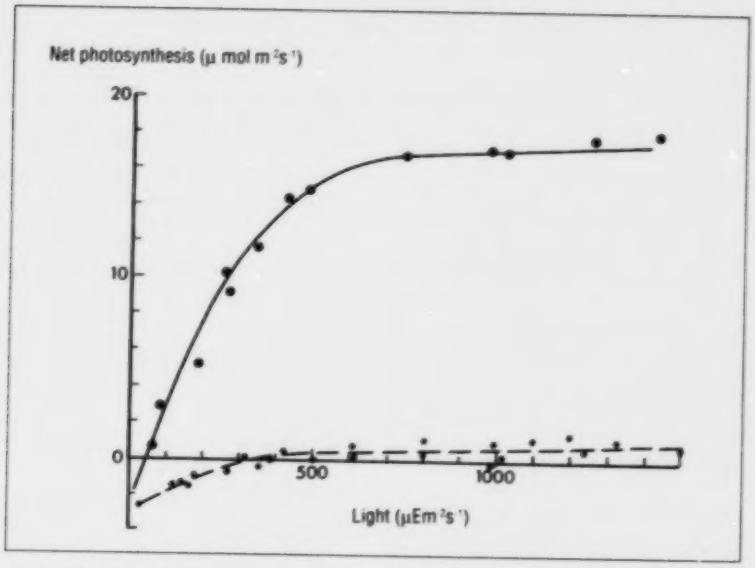


FIGURE 38. Net photosynthesis for Scots pine seedlings before (——) and after (— —) freezing to -7° C. No seedling damage was visible (after Lundmark [1985]).

Low night temperatures which do not kill a seedling can inflict "invisible" damage and cause growth reductions.

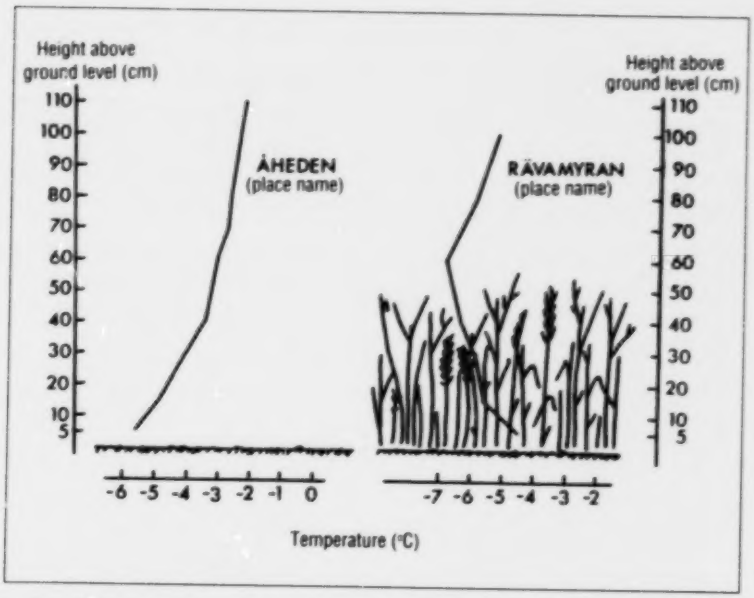


FIGURE 39. Profile of minimum temperatures over lichen-dominated (Åheden, Vindeln) and grass-dominated (Rävamyran, Vindeln) vegetation layers. Cold nights during the summer of 1982 (after Lundmark [1985]).

Cooling and subsequent frost risk are greatest near the ground surface or immediately above a dense vegetation layer.

heat storage capacity and thermal conductance, so air cooling will be less due to transport of heat up to the surface. The greatest surface cooling occurs when the soil is covered by insulating humus or grass.

Some reforestation steps that can reduce frost risk include maintaining a shelter overstory and site preparing to raise minimum temperatures.

3.2.2 Effect of site preparation

Site preparation can influence minimum air temperatures by removing the insulating humus/vegetation layer or by elevating the planting spot.

Patch scarification results in minor increases in minimum air temperature. Increases are limited to the shallow layer 5-10 cm above the ground (Figure 40). Scalping or blading large patches has a greater effect even at higher heights (Lundmark 1982). Mounding provides increased outgoing radiation as well as a raised planting spot with more air convection. Differences in minimum air temperatures between plowed and patch-scarified spots can reach up to 5-6° C (Rigner and Sundin 1985). The greatest benefits of site preparation in preventing frost damage occur in early summer when soil warming during the day is high. These benefits diminish in the autumn and, in some cases, are negative late in the autumn. In autumn, outgoing radiation exceeds incoming radiation and frost risk may be increased on prepared spots.

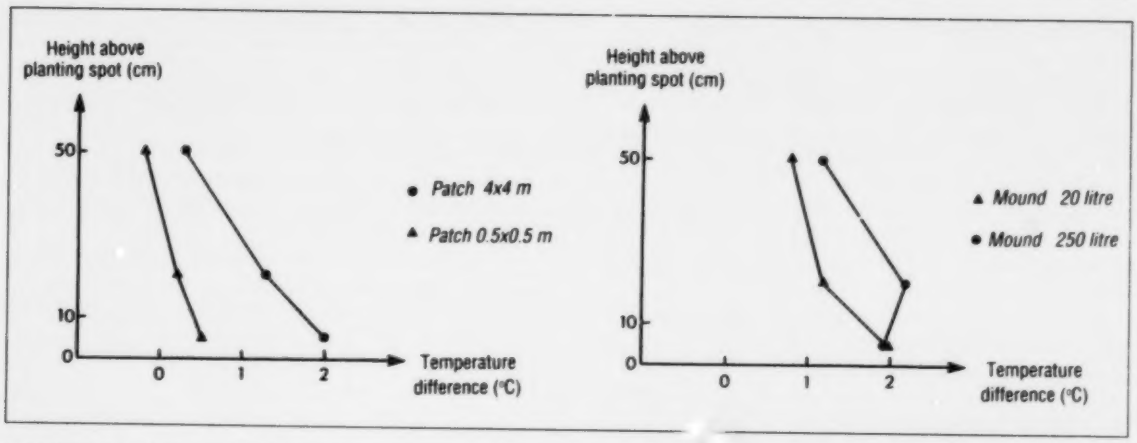


FIGURE 40. Differences in minimum air temperatures between scarified patch and untreated spots at different heights (after Lundmark [1982]).

Small patches have almost no effect on minimum air temperatures. Large patches or raised planting spots provide significantly higher minimum temperatures.

Early summer frost damage on a young Norway spruce. Photo: Göran Örlander.

3.3 Pine Weevil

The pine weevil (*Hylobius abietis*) often causes high mortality in forest regeneration in Sweden. Damage is greatest in the south, but it also reaches up into the northern Interior. The greatest problems occur during the first 3 years following harvest and then diminish with time.

Severe weevil attack directly kills seedlings by girdling, though it is more common that seedlings are just damaged. Damaged seedlings naturally have poorer survival and growth than undamaged seedlings (Figure 41).

Removal of humus and vegetation layers by site preparation can reduce pine weevil attack (Lekander and Söderström 1969; Söderström *et al.* 1978). The reason may be the weevil's supposed aversion to exposure, or its avoidance of warm mineral soil (G. Nordlander, pers. comm.). This would explain why weevil attack is lower with mounding than with patch scarification (Figure 42). The site preparation work should be of good quality and the seedlings should be placed at least 15-20 cm from the edge of undisturbed humus (Figure 43).

Weevil damage can be reduced without site preparation if large seedlings are planted or if seedlings are protected mechanically or chemically (Figure 44).

Poorly established seedlings have poor resistance to the pine weevil (Eidman 1986). The negative effects of weevil attack can be reduced if good site preparation has improved seedling vitality.

The effect of site preparation on other insect attacks is not well known. Söderström (1978) found that *Strophosomus papitatum* attacks increased following mounding. In the same study, however, *Hylastes brunneus* damage was not affected by site preparation.

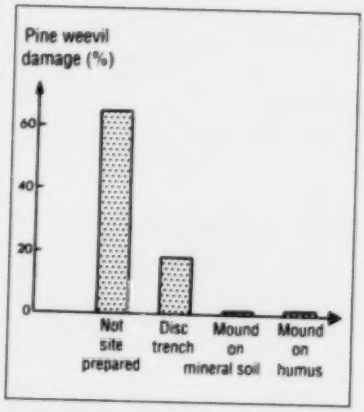


FIGURE 42. The effect of site preparation method on frequency of pine weevil damage (after Söderström et al. [1978]).

Site preparation, especially mounding, reduces pine weevil damage.

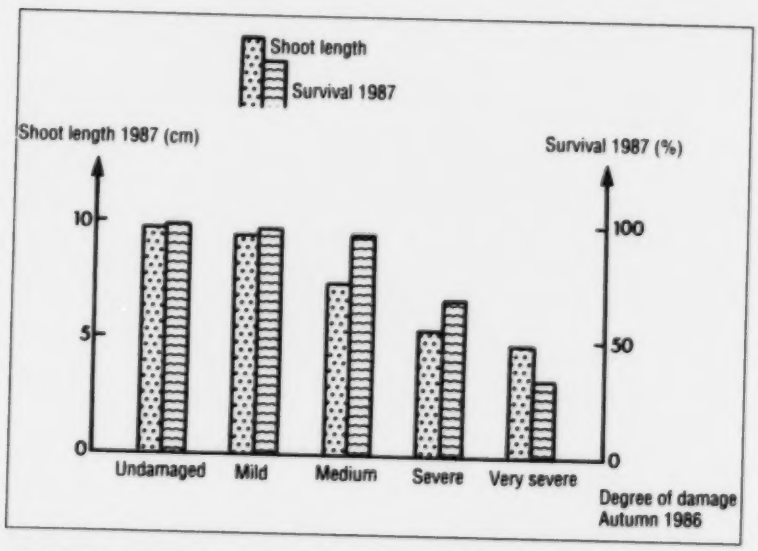


FIGURE 41. Growth and survival of seedlings affected by pine weevil (Hylobius abietes) damage. Damaged assessed just after it occurred and inventoried the following year. Norway spruce 2+0 stock treated with Ambush® at Växjö (southern Sweden) (after Örlander [unpublished data]).

Pine weevil attack causes both mortality and reduced growth.

3.4 Vegetation

3.4.1 Seedling reaction

Stand establishment is impaired by vegetation on many sites. The Swedish national forest inventory classes the proportion of rich sites with competing vegetation as follows: N. Norrland 17.6%, S. Norrland 35.2%, central Sweden 43.6% and southern Sweden 52.7% (Hägglund and Svensson (1982). Afforestation of agricultural land also involves problems with competing vegetation.

The negative effects of vegetation on seedlings are:

- competition for water and nutrients;
- effects on incoming solar radiation (light and temperature);
- allelopathy;
- mechanical impacts; and
- indirect effects (e.g., increased susceptibility to fungus, insects and voles).

Vegetation problems in reforestation have received the most attention internationally in drier areas of the world, such as Australia and New Zealand, where there is strong competi-

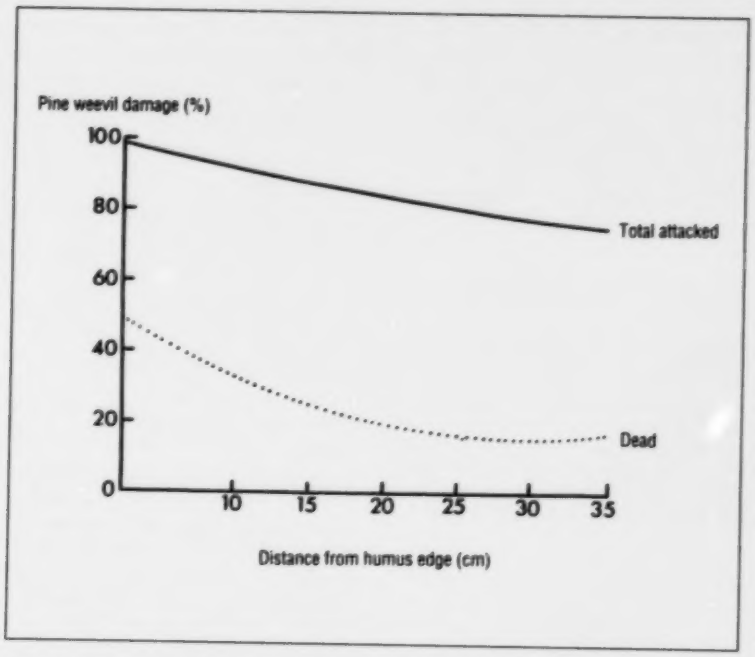


FIGURE 43. Extent of pine weevil attack in relation to the distance from the humus edge (after Berg et al. [1981]).

If the planting spot is within 20 cm of the humus edge, the risk of pine weevil attack increases.

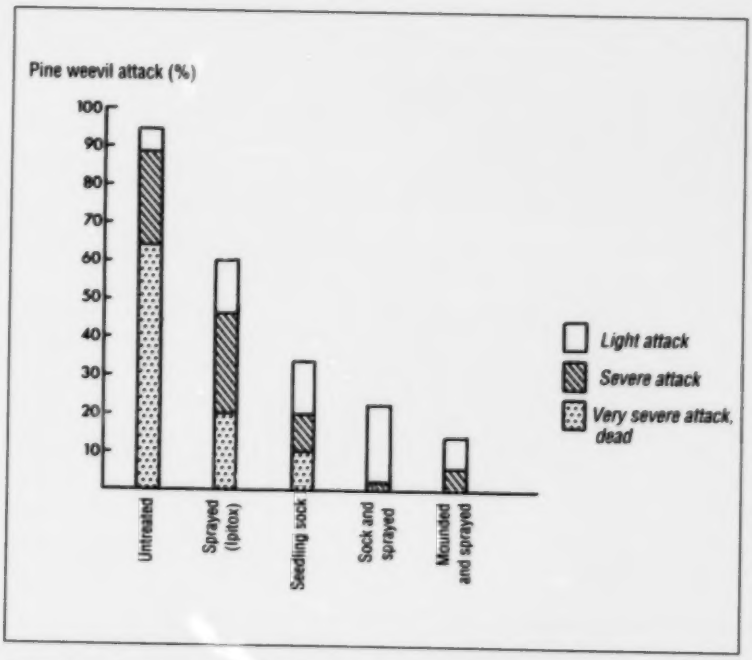


FIGURE 44. Pine weevil impact on seedlings treated with chemical and mechanical protection. Planted with mounding and without site preparation on a fresh site near Ulricehamn. (after Axelsson [1987]).

Pine weevil attack can be reduced with chemical or mechanical treatments. Combination of treatments further reduces impacts.

tion between grasses and seedlings for water. Transpiration from vegetation, especially grasses, can deplete soil moisture creating problems with seedling water uptake, which can result in subsequent reductions in growth and survival (e.g., Sands and Nambiar 1983).

Strong vegetation competition can affect seedling nutrient uptake. Bärring (1967) found that the nitrogen content of seedlings growing on herbicide-treated sites was 1.9% compared with 1.2% on untreated sites. A heavy cover of vegetation reduces the amount of solar radiation reaching the seedling. Site preparation can increase the light reaching seedlings and surrounding soil (Figure 45). This affects soil warming, among other factors (cf. Figure 9).

A dense growth of vegetation provides a favourable environment for damaging agents (e.g., weevils). Often the best seedling growth is obtained when the environment surrounding the seedling is kept vegetation-free (Figure 46).

3.4.2 Effect of site preparation

Revegetation of a cutover site depends on the vegetation and seed bank existing on site at the time of harvest (Granström 1985). Therefore, the distribution of species and the rate of invasion vary greatly between different sites (cf. Ingelög 1974). Site preparation affects both the vegetation coverage and distribution of species (Hagner 1965; Kardell 1987) (Figure 47). Patch scarification reduces vegetation immediately around seedlings; mounding or plowing (berms) further reduces invasion (Ferm and Sepponen 1981) (Figure 48). Slow revegetation of mounds and berms may be due to the lower soil moisture and higher surface temperatures imped-

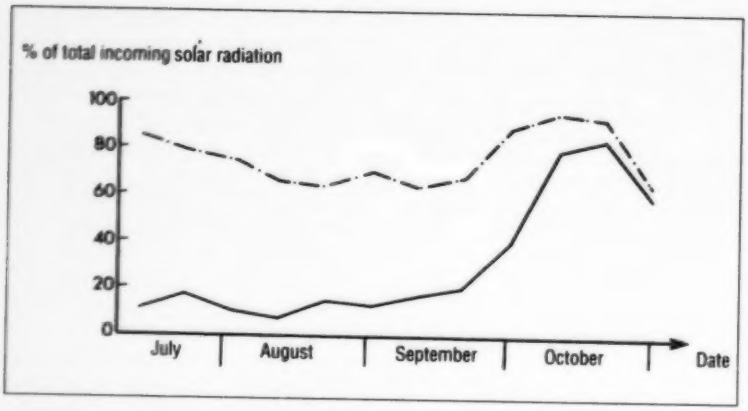


FIGURE 45. Incoming solar radiation to seedlings planted on mounds (—· —) and without site preparation (———) on a brushy site near Prince George, Canada (after Draper et al. [1985]).

On brushy sites, mounding increases incoming light to seedlings.

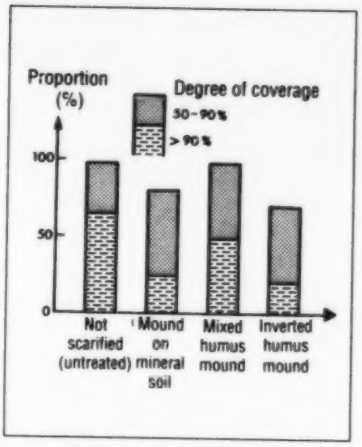


FIGURE 48. The invasion of vegetation (mostly Deschampsia flexuosa) 2 years following site preparation treatments. The proportion of planting spots with 50-90% and more than 90%, respectively, of surrounding area covered by vegetation, near Växjö (after Örlander [unpublished data]).

Mounding can reduce vegetation problems.

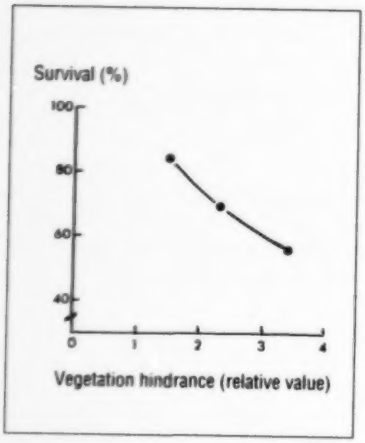


FIGURE 46. The relationship between vegetation hindrance and survival (after Bärring [1967]).

Survival is usually improved if the area surrounding a seedling remains vegetation-free.

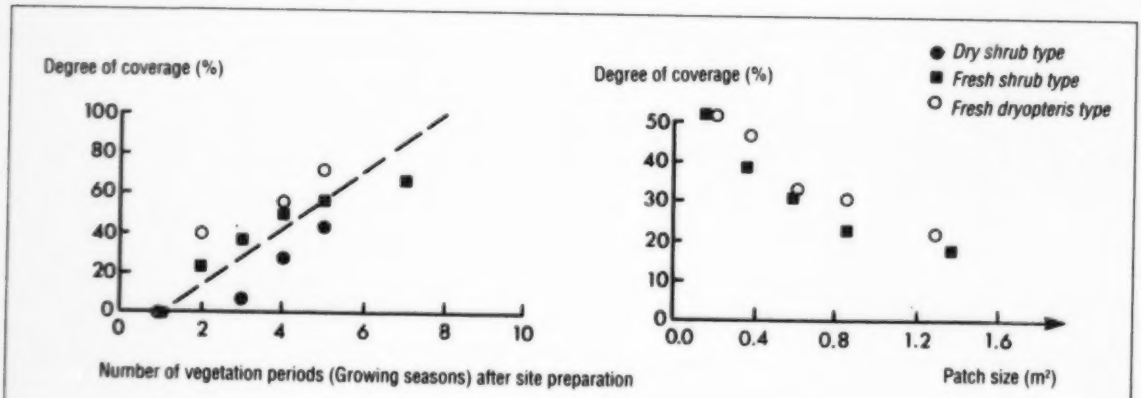


FIGURE 47. The invasion of vegetation and degree of coverage in different sized patches 4 years following site preparation in central-northern Sweden (after Hagner [1965]).

Scarified patches (especially small ones) are quickly invaded by vegetation, even on forest sites with relatively small vegetation problems. This significantly affects the application of sowing or natural regeneration.

ing germination (Sims 1975). However, site preparation seems to favour natural germination of broadleaved species (Fries 1984) (Table 2).

Exposed mineral soil, especially fine-textured soil, is a good environment for birch seed germination. Mixtures of humus and mineral soil or pure peat are also favourable for germination (Palo 1986).

The occurrence of voles is favoured by a dense vegetation layer. Thus, as Bärring (1967) found, vole damage can be decreased and survival increased if vegetation is scraped away before the forestation of old fields.

Despite the detrimental effects on seedling growth, competing vegetation does play an important role in biological recycling, the uptake of liberated nutrients and limiting nutrient leaching. Therefore, spot-wise vegetation control is preferable to complete control of vegetation over an entire area.

TABLE 2. Seedling establishment of birch expressed as % of germinable seed one year following sowing (after C. Fries [1984])

	Patch	Mound	Burning	No Site Preparation (untreated)
Dry site	0.3	0.1	0.1	0
Fresh site	6	2	0	0
Wet site	16	21	7	3

3.5 Allelopathy

Allelopathy means that certain plants have other negative influences on seedlings besides competition for nutrients, water, light, etc. It can involve the secretion of growth-impeding substances or the production of toxic substances in the litter. In recent years several common forest plants have been found to hinder germination and growth of conifers (O. Zackrisson, pers. comm.). Crowberry *(Empetrum nigrum)* probably has the most negative effects. A single crowberry leaf can inhibit germination of Scots pine seed and leachate from leaves can reduce growth. Other plants with allelopathic qualities include kinnikinnick *(Arctostaphylos uva-ursi)*, some heathers, reindeer lichens, and bracken *(Pteridium aquilinum)* (O. Zackrisson, pers. comm.). Regeneration of areas with allelopathic plants should be mechanically site-prepared to remove the vegetation or burnt. Burning also removes allelopathic material in the litter.

SITE PREPARATION METHODS

- *The methods discussed in this section include planting without site preparation, patch scarification, disc trenching, mounding, plowing, and complete plowing.*

CHAPTER 4

The following section deals with the effects of some site preparation methods and comments on their application. Prescribed burning and chemical site preparation methods are not addressed in detail. Some recommended Swedish reports on burning include Lundmark (1988), Körlen and Kardell (1987), Kardell and Laestadius (1987), Uggla (1973), and Sirén (1973b).

Herbicide treatments have received very little attention in Sweden in recent years despite good results on vegetation-rich sites (Bärring 1967). Chemical site preparation methods have been used extensively in other countries such as Canada, USA, New Zealand, and Australia.

4.1 Planting Without Site Preparation

Although survival and growth are better on most site types if planting is done with site preparation than without, some new techniques developed in recent years for planting without site preparation have produced favourable results. Hagner and Lindberg (1984), for example, reported favourable results from planting with plastic casings (PUM) which provide protection from insects and desiccation. Use of PUM casings resulted in better planting results both with

Seedling planted with insect and desiccation protective casing (PUM). The method facilitates surface planting in the humus. Photo: Mats Hagner.

and without site preparation. On brushy sites in southern Sweden, however, PUM casings have not provided adequate protection from pine weevils or competing vegetation (Hagner and Hansson 1987). Planting with weevil protection such as plastic collars (Lindström *et al.* 1986) or nylon socks (Nilsson 1985; Axelsson 1987) can give good results without site preparation.

To reduce the effects of competing vegetation, planting should be carried out directly following harvest. This method, "green slash planting" (Ståål and Franzon 1961), was developed in southern Sweden and uses large 2+2 spruce stock and a special planting technique that employs a boring tool. Lindman and Nordström (1964) showed that planted spruce seedlings had better development in green slash than without slash. This result was verified by Andersson (1976), though Leijon (1985) could not find any positive effects on survival and growth the first years following planting. Some of the observed advantages of planting in green slash include the preservation of soil moisture, slightly higher humidity and initial shading around the seedling. Disadvantages include increased risk for pine weevil damage, low soil temperatures, and delayed thaw of soil frost in late spring.

Planting without site preparation has the greatest application on sites that are difficult to mechanically site prepare and sites that have thin humus and little vegetation. It may also be a good method for sites prone to frost heaving. Planting should be carried out immediately after harvest and should involve weevil protection. The need for high quality stock is greater without site preparation. Large vigorous stock and good quality planting are required. The preferred species for planting without site preparation is Norway spruce.

4.2 Scarified Patch and Disced Trench

As a rule, patch scarification and disc trenching provide a better establishment environment than undisturbed ground (Bärring 1965). Removal of the humus layer provides increased soil temperatures and more secure moisture availability. Scarified patches or disced trenches result in small increases in minimum air temperatures, so frost risk is seldom decreased. Patch scarification and disc trenching do not loosen the soil significantly below ground level, and where loosening does occur, it does not last long. In some cases, removal of the humus layer can lead to a more compact planting spot since the top loose layers are displaced. Patch scarification and disc trenching usually create planting spots below the ground level (ex. Berg *et al.* 1981). This can place roots in an oxygen-poor environment.

The patch size and distance to the humus edge can affect the planting result. As mentioned above, the planting spot should be 15-20 cm from the humus edge to reduce pine weevil damage (cf. Figure 43). An increase in patch size reduces vegetation competition. However, excessively large patches can be negative for seedling development, especially for spruce. Söderström *et al.* (1979) determined optimal patch size to be 25-35 dm^2, that is 50-60 cm per side. Spruce, whose performance can be suboptimal in pure mineral soil, should be placed as close to the humus edge as possible, considering the risk for weevil attack.

As a rule, better results can be obtained through the use of elevated positions on the patch or trench profile (Berg *et al.* 1981; Hagner 1985). However, a study by Bäcke (unpublished data) indicated that elevated planting spots by themselves were not entirely positive unless the spot was "loosened".

The main difference between patch scarification and disc trenching is that the latter creates a greater number of plantable spots per hectare. It also results in greater natural regeneration of birch and a larger proportion of ground that is disturbed. Disc trenching is preferable to patch scarification on operationally difficult sites

Disc trenching. Photo: Leif Öster.

(i.e., those with a high frequency of stones, slash, etc.). Patch scarification should be used where harsh site preparation is best avoided, such as on dry or thin humus sites.

4.3 Mounding or Elevated Berm

Mounding is a good site preparation method on most site types in Fennoscandia. Mounds can be formed either on mineral soil or on (inverted) humus. Mounds have higher soil temperature and are well-drained. The soil stays loosened for a long time, especially if humus material is mixed with the soil or if there is mineral soil capping over inverted humus. This ensures good oxygen availability to the seedling. Mounding also often reduces the vegetation competition. The warm, dry mound surface is not a favourable germination environment for competing species; and grasses and herbs tend not to fall on the elevated spot when they wither in the autumn.

Mounding also reduces the risk of weevil attack compared to that which occurs with disc trenching or patch scarification. (The effects of mounding on other kinds of insect attacks are not well understood.) As well, mounds or plowed berms have been shown to reduce impacts from voles.

A disadvantage of mounds is that those formed on mineral soil have a greater risk of frost heaving than do those sites prepared by patch scarification. Even if mounds are formed on inverted humus, the risk of frost heaving can be significant.

Mounding with intermittent or spot application has a relatively small effect on the site's nutrient and moisture regimes. If soil is piled in continuous berms, there can be significant influences on nutrient cycling. Mounding that is carried out at the same time as ditching with an excavator can strongly influence the site nutrient regime and hydrology. This method should be reserved for wet, thick humus sites.

Positive effects of mounding have been reported for a long time, for example, by Wahlgren (1914) and in Latvia in the 1930's (Buss 1932; Ovsjankins and Kaninskaja 1960). Many mounding experiments were

Mounding. Photo: Erland Charlesworth.

established in the 1970's. Ongoing Swedish experiments show positive results with the technique (Figures 49-51), however there are situations where some mounds on undisturbed humus or inverted humus can be problematic.

4.4 Mounding on Mineral Soil or Humus

Mounding can be done either on mineral soil or on humus (inverted humus). The main reason for planting on inverted humus is to derive the benefits of liberated nutrients from the buried humus. The problem with these kinds of mounds is that they can dry out and lead to water stress (Figure 52). Early site preparation experiments used mounds placed directly on

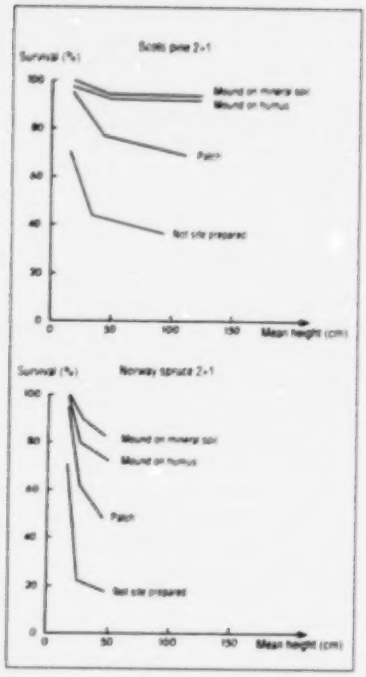


FIGURE 50. Mounding experiment at Orrefors established in 1974. Sandy (silty) moraine, fresh site. Mound size approx. 15 L. Inventoried in 1974, 1976, and 1979. For further details see Söderström et al. (1978).

Mounding has given good results in southern Sweden largely by reducing weevil attack.

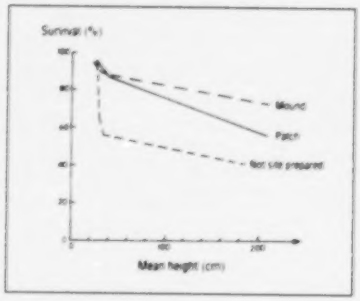


FIGURE 51. Mounding experiment at Vindeln (northern Sweden) established in 1976. Sandy (silty) moraine, fresh site with Scots pine 2+1 stock. Planted at three times: spring, summer and fall. Inventoried in 1976, 1977, 1978, 1980, and 1987 (after Örlander [unpublished data]).

The benefits of mounding remain after several years. In this experiment, patches and mounds gave similar results for the first 5 years. After 12 years, mounding proved to be the better method.

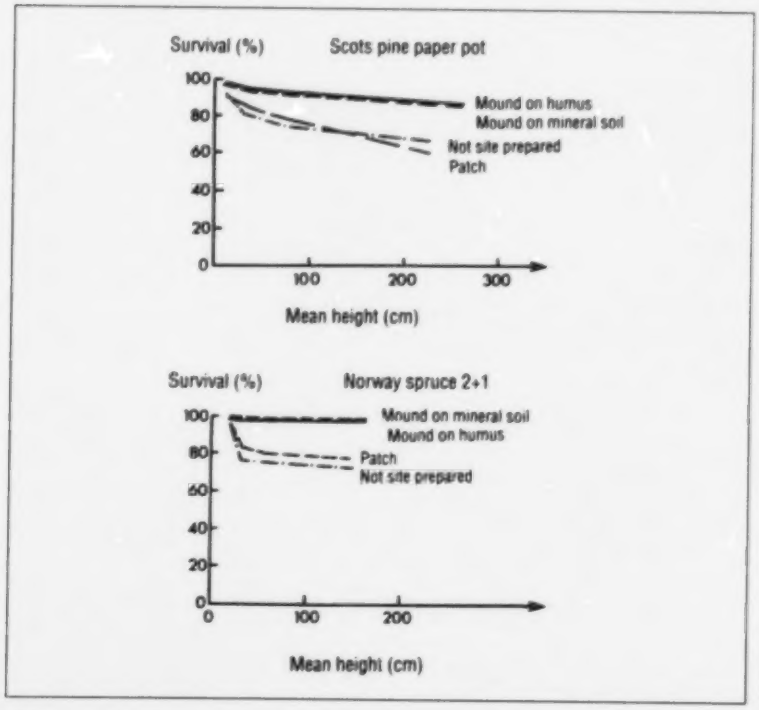


FIGURE 49. Site preparation experiment at Djupliden (northern Sweden) established in 1973. Sandy (silty) moraine, fresh site. Mound size approx. 15 L. Inventoried in 1974, 1976, 1979 and 1985. For further details see Söderström et al. (1978) and Örlander (1987).

One of the oldest Swedish mounding experiments. Mounding has been a superior method compared to patch scarification.

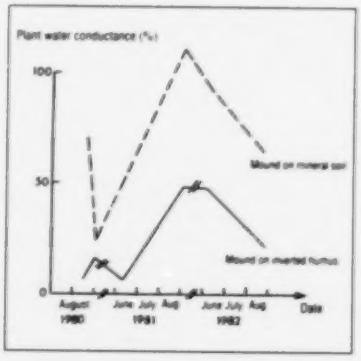


FIGURE 52. Plant water conductance for seedlings planted in inverted humus mounds and mineral soil mounds. Percent of plant water conductance of established seedlings (after Örlander [1996a]).

The study shows that inverted humus mounds can be so dry as to cause water stress for seedlings.

undisturbed humus. Despite lower survival with such mounds due to desiccation (Figure 53), these mounds have been unfairly compared to mounds on mineral soil.

If planting is done deeper than normal (5-10 cm under ground surface), then water stress in inverted humus mounds can be reduced (Figure 54). As a rule, frost heaving occurs less in inverted humus mounds than in mineral soil mounds. Mounding on inverted humus should be used mainly on moist-wet sites or areas with high precipitation. On soils sensitive to frost heaving, seedling roots should be planted into the upturned humus. On dry sites or areas where potential evaporation is greater than precipitation, mounding should be avoided or combined with deep planting. On mineral soil, it should be avoided on soils susceptible to frost heaving. It should be used mainly on fresh sites.

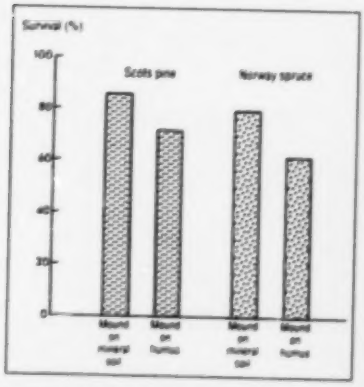
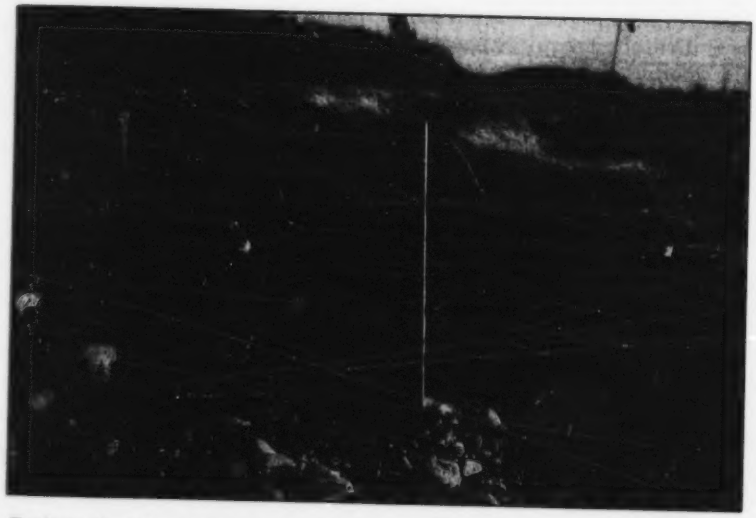


FIGURE 53. Survival of seedlings planted in mineral soil mounds and mounds on humus (not inverted) after 2 years (after Frelj and Örlander [1987]).

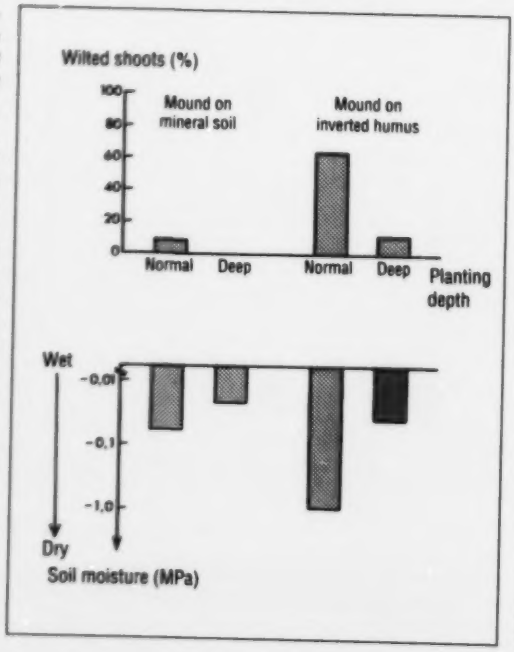
Mounding on humus can result in lower survival, mostly because of desiccation.



Early spring damage on a seedling planted high up on a large excavated mound. No visible damage occurred on the shaded seedling. Photo: Christer Wilhelmsson.

FIGURE 54. The proportion of seedlings with wilted shoots and soil moisture at 10 and 20 cm depth during a dry period in June. Planting depths were normal and deep (plug top 2 and 10 cm below surface, respectively). Mounds (15 L) formed partly on mineral soil and partly on inverted humus. Spruce 2+0 plugs, near Växjö (southern Sweden), (after Örlander [unpublished data]).

Inverted humus mounds can dry out during dry years. This can be alleviated by deep planting through the inverted humus.



4.5 Mound Size and Planting Spot

Most mounding experiments have used relatively small mounds (10-20 L). If mound size is increased, temperature and drainage in the root zone are little affected. Large mounds have mostly been used in combination with ditching and excavators. The advantages of large mounds over small mounds include reduced frost risk, better long-term drainage, and, in some cases, reduced vegetation competition. On the other hand, large mounds have the disadvantages of increased risk for frost heaving and early spring damage.

In British Columbia, McMinn (1985, unpublished data) found that an increase in mineral soil

capping up to 15 cm on inverted humus mounds was beneficial for seedling performance. In Finland, a 20-cm capping of mineral soil is considered desirable (Mälkönen 1986). It has been observed that large mounds formed with excavators effectively compress slash and porous humus layers, which is advantageous for water supply in the mound. Normally, the mineral soil capping should not be thicker than required to press the mound firmly against the ground and to deter weeds from the humus layer surfacing through the mound. The latter refers to soil profiles of mineral soil (podsols). Mounding on cultivated soils or Mull soils can exacerbate weed problems.

The optimal planting spots for seedlings on mounds vary with site type. Planting depth has great significance and can be the deciding factor on soils sensitive to frost heaving (Figure 55). Mounds offer several alternative planting spots. Figure 55 illustrates some examples of planting spots suitable to different site types. Mounding on fine-textured silty soils can be problematic, since the soil can dry out and crack in the mounds, causing desiccation and root damage. On that type of soil a good alternative is to plant directly into the inverted humus (cf. Adelsköld and Örlander 1989).

4.6 Plowing

Plowing is a radical site preparation method which can influence both the long-and short-term growth of seedlings. Plowing[2] (often referred to as "tilt" plowing) can provide long-term soil loosening. On a terrace or shoulder (see Appendix 2), however, soil is often too compact for successful planting.

[2] Most plowing in Fennoscandia is done by models of the Marttini plow.

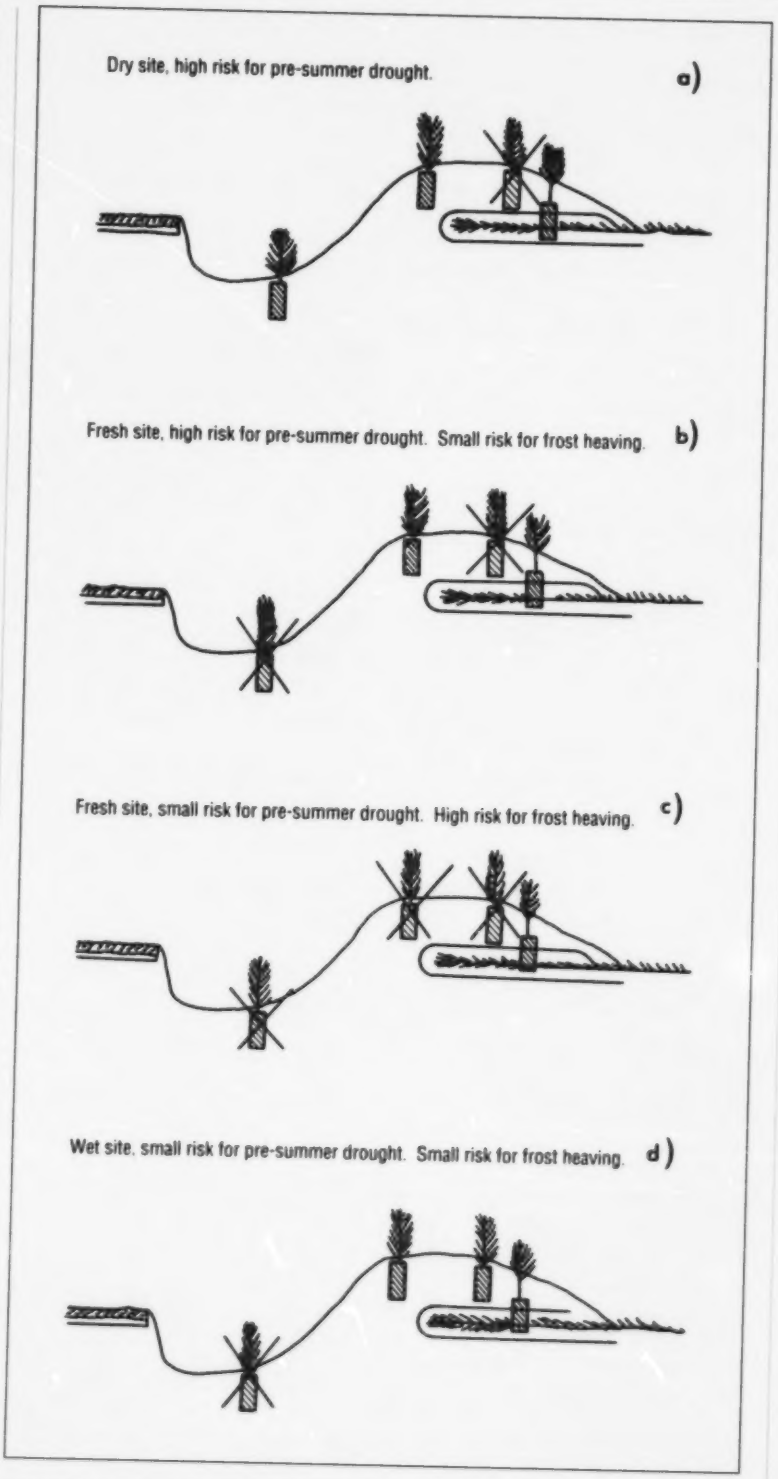

Dry site, high risk for pre-summer drought.
a)
Fresh site, high risk for pre-summer drought. Small risk for frost heaving.
b)
Fresh site, small risk for pre-summer drought. High risk for frost heaving.
c)
Wet site, small risk for pre-summer drought. Small risk for frost heaving.
d)

FIGURE 55. Some examples of suitable and unsuitable planting spots on inverted humus mounds for some site types. Unsuitable spots are crossed out.

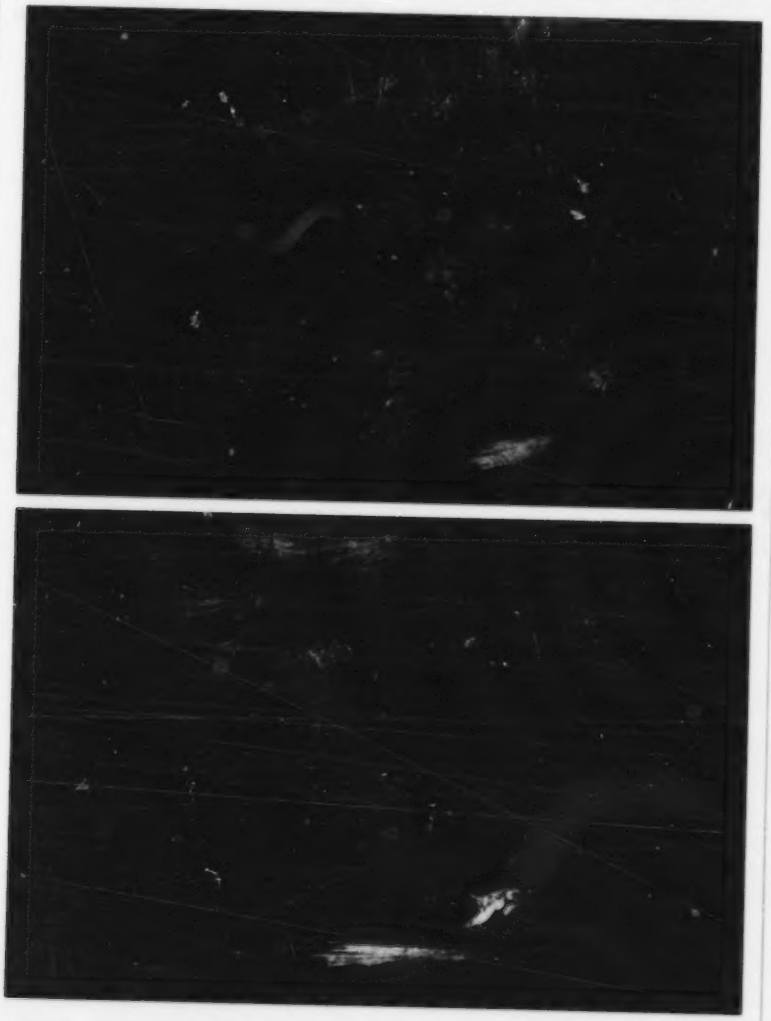
Loosening and drainage in berms gives seedlings good oxygen availability and raises soil temperatures. Plowing is advantageous in minimizing the risk of frost damage, since minimum air temperatures above the mineral soil are high compared to those achieved with other methods. Plowing also tends to reduce competition from vegetation, especially if seedlings are planted in berms. However, broadleaved species and other vegetation can easily regenerate in plowed areas on wet sites (Sahlén 1975). Frost heaving can be a problem if seedlings are planted on the terrace or in a deep mineral soil capping on the berm.

Weevil damage is usually decreased with plowing because of the large exposure of mineral soil.

Plowing rapidly liberates nutrients from slash and humus. This mineralization of nutrients starts about 1 year following treatment and continues for about 10 years, depending on site conditions. For seedlings to use these nutrients, large vigorous seedlings which start up quickly should be planted.

The main establishment problems with plowing are desiccation (when seedlings are planted in berms), frost retention under berms, and early exposure to wind and sunlight. However, plowing gives very good establishment results on many sites (Figure 56).

The increased nutrient mineralization following plowing seems to favour spruce in particular. The greatest advantages of plowing compared with patch scarification or disc trenching occur on wet sites (Table 3).



Seedlings planted in different positions after mounding (100 litre volume) photographed in the autumn (above), and following spring (below) after planting. Seedlings in the bottom of the depression suffered from oxygen deficiency and the higher, exposed seedlings were hit by early spring damage. Photo: Christer Wilhelmsson.

4.6.1 Plowing: the debate continues

Plowing (tilt) is the site preparation method that most strongly affects the soil's nutrient regime and water balance. This is positive for long-term productivity if the site is wet or if there is a thick, inactive humus layer (i.e., little or no nutrient cycling). The method is considered unsuitable for nutrient-poor or dry sites. On normal forest sites it is impossible to say for certain if plowing is bad for the long-term productivity given today's knowledge. No negative results on growth have been reported from the early plowed regeneration areas in Sweden which are about 20 years old.

Mortality has been observed in young stands on plowed areas in northern Finland and one hypothesis attributes this to phosphorous deficiency (Tikkanen 1987). Lähde (1984) has theorized that seedlings are damaged by heavy metals and aluminum which are liberated when the soil is inverted. However, these mortality rates with plowing are not

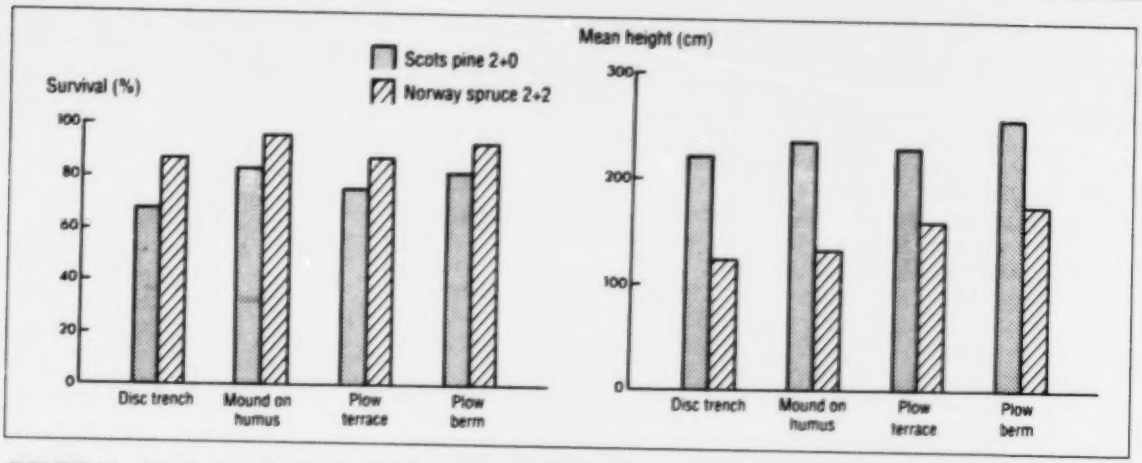


FIGURE 56. Survival and height of Scots pine and Norway spruce 13 years after planting with different site preparation methods. Sandy (silty) moraine, fresh-moist shrub type site near Lycksele (northern Sweden). For further details see Söderström et al. (1978) and Örlander (1987).

Plowing gives good survival and growth, especially for seedlings planted in the berm.

TABLE 3. The effects of some site preparation methods. Survival and growth after 13 years for Norway spruce seedlings planted in fresh and wet sites. Sandy (silty) moraine, near Lycksele. For further details see Söderström et al. (1978) and Örlander (1987).

	Survival (%)		Height (cm)	
	Fresh site	Wet site	Fresh site	Wet site
Disc trench	90.0	75.6	122.5	125.7
Mound on humus	94.8	100.0	128.6	141.4
Plow, terrace	91.3	85.4	160.9	157.2
Plow, berm	93.3	95.3	172.4	184.0

alarming compared to those with other methods (e.g., Heikillä 1981; Pohtila and Pohjola 1983, 1985; Pohtila and Valkonen 1985).

One problem that has been observed with plowing is one-sided root development (Björkdahl and Sandewall 1976, Sundkvist 1988). This can lead to instability problems and windthrow (Savill 1976).

On fine-textured soils, especially silts, plowing should be avoided because of the risk of soil slumping.

Few silvicultural methods have been debated so heatedly as plowing. Special permission must be granted in Sweden to plow. Plowing involves a drastic change in flora and fauna. It affects wildlife use of habitats, such as reindeer grazing. A special problem with the disruption of the soil profile is that archaeological remnants can be disturbed. Undoubtedly, future access and landscape aesthetics are also affected by plowing.

The length of time that "strips" or berms remain visible after plowing depends on the soil type and moisture, the formation and thawing of frost, the slope, the precipitation, and the time since plowing. It has been found that plowed furrows do gradually fill in as the berms flatten out (Sirén 1973a; Ferm and Sepponen 1981).

4.7 Berm Formation and Planting Spot

Normally, planting is done on the berm (tilt). Modern plows no longer create terraces. Berms provide a better growth environment and less risk for one-sided root development than do terraces over the long term.

Seedling development on the north terrace (south aspect) has been shown to be better than on the south terrace as a result of greater reception of solar radiation and higher soil temperatures. It has therefore been recommended that plowing be carried out in a north-south orientation for even seedling development. This has little significance with planting on top of the berm.

The optimal plowing depth and thickness of mineral soil cap has received much attention. In Finland a capping of 20 cm is recommended. Current plowing implements press berms down considerably, so the problem with poor capillary contact is diminished along with the need for a thick capping. If there is a risk for frost heaving, seedlings should be planted deep into the humus and capping should

not be too thick.

Normally, plowing is done in the autumn and planting in the following spring. Waiting a few more years before planting can improve the capillary contact and water relations in the berm and reduce the risk for frost heaving since the soil "settles itself". However, Pohtila's (1977) series of experiments in Finland showed there were disadvantages to waiting too long before planting. Competing vegetation becomes established and soil loosening diminishes.

In summary, it can be said that plowing generally gives very good results with planting. Its application should be limited on poor, dry sites because of negative effects on long-term productivity, and on sites with nature concerns. Plowing should be applied foremost on areas where it gives superior results over other methods, notably areas where precipitation exceeds potential evaporation with thick humus, or wet sites.

4.8 Deep Plowing and Complete Plowing

Complete plowing[3] has not been commonly used with forest regeneration in Sweden. The method has had varying results with the planting of old agricultural fields. The greatest problem with complete plowing of cultivated soils is the flush of competing vegetation after the treatment.

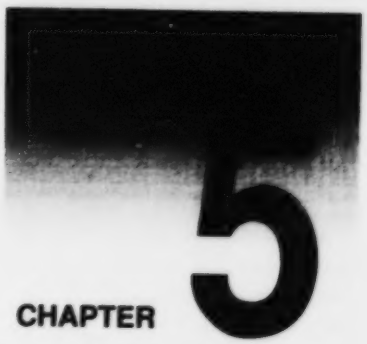
Deep plowing has been used to establish forests in Germany, Scotland, Australia, New Zealand, and several other countries. It has mainly been applied where the soil profile is not favourable for root development. In Sweden it has not been used extensively because of the high frequency of stones. If the soil profile can be worked, however, it can be a very good method, e.g. on agricultural soils with hardpans.

---

[3] Plowing with agricultural type plow (see Appendix 2).

SITE PREPARATION ON SPECIAL SITE TYPES

- *Agricultural land (old fields) and peatlands differ from normal forest sites in terms of what technical alternatives are available for treatment and what can be expected following site preparation. Problems with vegetation and frost are common on both kinds of sites. The easily cultivated soil facilitates the use of relatively radical site preparation treatments.*



5.1 Old Fields

Vegetation, rodents, and frost are major problems associated with planting in old fields. Patch scarification can reduce vegetation competition immediately around a seedling, but the effect is short term and the method is not suitable on wet or fine-textured sites (cf. Bärring 1962, 1967; Söderström 1979).

Plowing (tilt plowing) is the preferred preparation method for afforestation of old fields. Good results have also been shown with complete plowing on fields without heavy couch grass or weeds that rapidly reproduce vegetatively (Bärring 1962). Plowed berms with mineral soil capping thin enough to allow roots to contact the buried substrate have been favourable for planting (Bärring 1967). Berms reduce vegetation competition and improve temperature and moisture relations.

Seedlings should never be planted in plowed furrows because of the risk of smothering by grass. Those planted in thickly capped berms (entire root system in the berm) have shown poorer development than seedlings planted in thin berms mostly because of desiccation and persistent soil frost. Early spring damage can be a problem in thick berms or with poorly developed seedlings (Bärring 1967).

Mounding with ditching can be suitable for old fields since these sites are often wet. The choice of mound size and planting spot would be influenced by the same factors mentioned above.

There are several herbicides which can be used with planting in fields. Many studies have demonstrated good results when competing vegetation is chemically treated. Deep plowing below top soil can also repress competing vegetation. Furthermore, if vegetation is held back by plowing or chemical treatment, vole attacks can be significantly reduced (Bärring 1967).

Large seedlings should be used for planting fields because they withstand vegetation competition better. An example of seedling sizes required to avoid treatment for grass competition is shown in Table 4.

Norway spruce is the preferred species for planting on old fields. The use of broadleaved species demands more intensive treatments to control damage from rodents and ungulates since they find deciduous trees are more attractive. Furthermore, many deciduous species are less tolerant to vegetation competition than are conifers (Davies 1987). Consequently, most deciduous species plantings in fields have failed. According to Leikola (1976), the same site preparation methods used with pine and spruce can be used with birch with significantly greater effects.

5.2 Peatlands

Peatlands can be divided into three categories having regeneration problems:

1. swamps which have not been treated by ditching or other measures, usually considered to be non-productive;
2. previously ditched sites bearing trees with high productivity and good growing stock;

TABLE 4. Recommended seedling size for planting old fields with varying vegetation competition (after Bärring [1967])

Degree of vegetation competition	Mean height of vegetation (cm)	Seedling size range (cm)
Low	25-50	25-35
Medium	30-60	30-40
High	50-75	50-60

3. "peatland hayfields", previously cultivated for agriculture, overlying peat.

The problems of reforestation differ according to the type of peatland. High water levels and frost risk are problems common to all peatlands, but both can be influenced by site preparation.

As a rule, previously ditched peatland has more humified peat than undrained peatland. Ditching advances humification and reduces hydraulic conductivity (Päivänen 1973). Reforestation of a previously forested peatland requires a functioning drainage system and an effectively drained planting spot.

Plowing with planting on the berm has consistently proven to be an effective method, especially on open peatlands (Bergman 1980). On previously ditched peatlands, the only alternative may be mounding with an excavator. Mounding is then done concurrently with the necessary ditch cleaning or additional ditching.

Frost damage is perhaps the greatest problem with reforestation of peatlands (Lundmark 1987). Risk of frost damage is especially high on ditched peatlands. These sites lie even lower in the terrain since settling occurs following ditching. It is generally necessary to use a shelter nurse crop or overstory to reduce risk of frost damage on peatlands.

Raising the planting spot (e.g., mounding) reduces the risk of damage to the seedling (Lundmark 1982). A radical treatment that removes surface layers also reduces frost risk (Braekke 1972). Because the risk of frost damage can increase on drained sites as a result of surface dryness, extremely low-lying sites should not be severely drained (Bergman 1980).

Peatlands are colder than mineral soils. Drainage worsens this temperature relationship even further (Kaunisto and Päivänen 1985). Frost can persist for 3-4 weeks longer in drained peatland compared with undrained peatlands (Bergman 1980). Site preparation can improve temperature relations.

Most peatlands are deficient in phosphorous and potassium. Potassium deficiency can increase the sensitivity of seedlings to frost (Burgtorf 1968). Fertilization of seedlings should be carried out at the time of planting on peatlands (especially with new ditching). The initial fertilizer application should always contain phosphorous and potassium, and on poorer sites, nitrogen. Recommended rates are 3-5 g nitrogen and 3-5 g potassium per seedling (Kaunisto and Päivänen 1985). Phosphorous should be spread in the form of raw phosphate: 20-40 g per seedling (Bergman 1980). Fertilizer should never be spread directly onto the root area, but in a ring 20-30 cm from the seedling.

Vole and ungulate damage are often problems on peatlands, and fertilization can increase wildlife damage (Kaunisto and Päivänen 1985). Control of vegetation by site preparation can be very worthwhile to prevent vole damage.

Site preparation for natural regeneration and sowing is seldom necessary. Sphagnum moss is a very good germination substrate. However, site preparation may be the deciding factor for success on previously ditched sites. Damage from frost heaving may be severe when highly humified peat is exposed (Kaunisto and Päivänen 1985).

So-called "peatland hayfields", are perhaps the most difficult peatlands to reforest. Formerly cultivated wetlands are usually deficient in potassium and other nutrients. Agricultural cultivation lowers the ground surface, which leads to even poorer off-site drainage of water and increased frost threat (Hannerz 1987). Vegetation on formerly cultivated wetlands is often dense and close to the surface, competing with seedlings and favouring voles.

Ditching and site preparation (plowing or mounding) in combination with fertilization are steps which should be taken with planting on these sites. Another alternative is to prepare the site and use natural regeneration of birch for a shelter nurse crop.

SEEDLING STOCK

- *The choice of stock type, both in species and size, affects the choice of site preparation method. For example, large seedlings manage better than small seedlings after planting without site preparation.*
- *The previous sections have dealt with site preparation without regard for stock type. This gives a simplified picture. Seedling material, size, and condition affect the choice of site preparation method.*

CHAPTER 6

6.1 Stock Size

Site preparation and large stock size can be partly exchangeable when it comes to influencing survival (e.g., McMinn 1985). Large seedlings can compensate for lack of site preparation. In southern Sweden, large 2+2 spruce seedlings are recommended for planting in "green slash". At the same time, large seedlings also benefit from site preparation.

In recent years, deep planting with mounding has received increasing attention. This technique requires relatively long rooted plugs. A change in site preparation method, for example, from disc trenching to mounding, also requires a change in stock type. It is important to see nursery cultivation and site preparation in an "overall" perspective.

6.2 Species

Different species have different environmental requirements for establishment. Species such as birch and pine usually react more positively than spruce to planting in humus-free patches or mounds. Spruce establishes well after site preparation where roots can readily contact humus material (Figure 57), and in more protected micro-sites (e.g., "green slash" planting). A well-

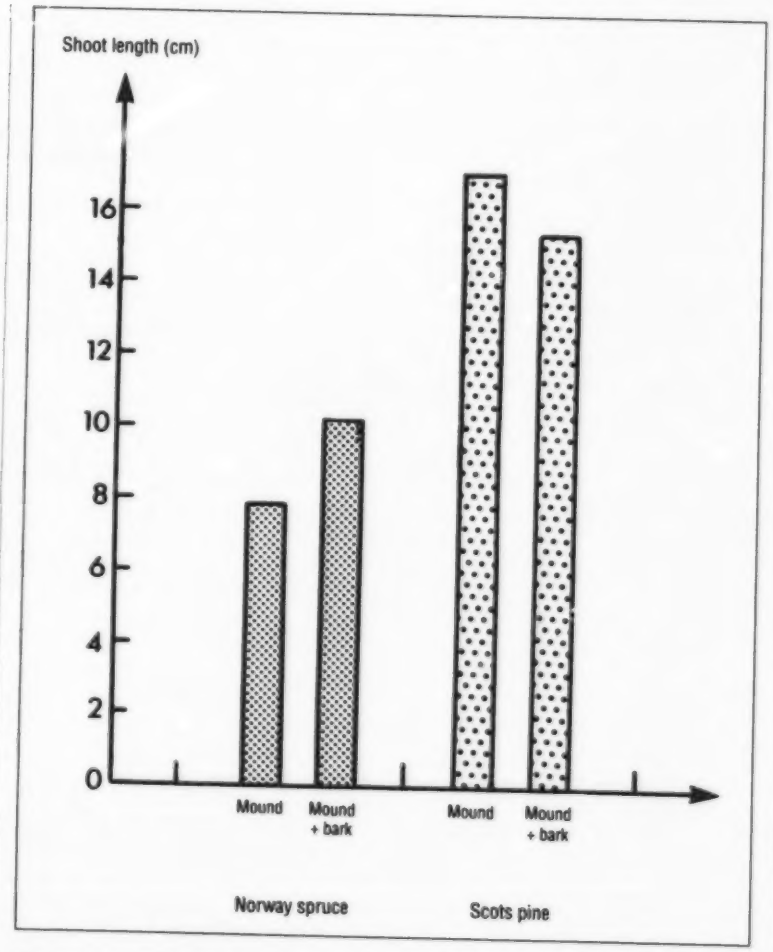


Figure 57. Terminal shoot length for Scots pine and Norway spruce planted in mineral soil mounds and mineral soil mounds covered with bark 2 years after planting near Växjö (after Örlander [unpublished data]).

The species have somewhat different site requirements. Covering with bark has produced increased growth on spruce and decreased growth on pine in this experiment.

known difference between species is the response after prescribed burning. Scots pine and silver birch are generally favoured after burning, while Norway spruce grows more poorly over the long term (Körlen and Kardell 1987) (Figures 58 and 59).

6.3 Mycorrhizae

Site preparation can affect the development of mycorrhizal fungi. A Finnish experiment by Mutka and Lähde (1977) found good mycorrhizae development after site preparation. The best development was found in totally cultivated treatments and the lowest was found after (tilt) plowing. The absence in the latter was probably due to periodic moisture deficits. A Swedish experiment did not find any differences in the amount of mycorrhizae around seedlings planted in disc trenches at varying distances from the humus edge and those planted without site preparation (A. Dahlberg, pers. comm.).

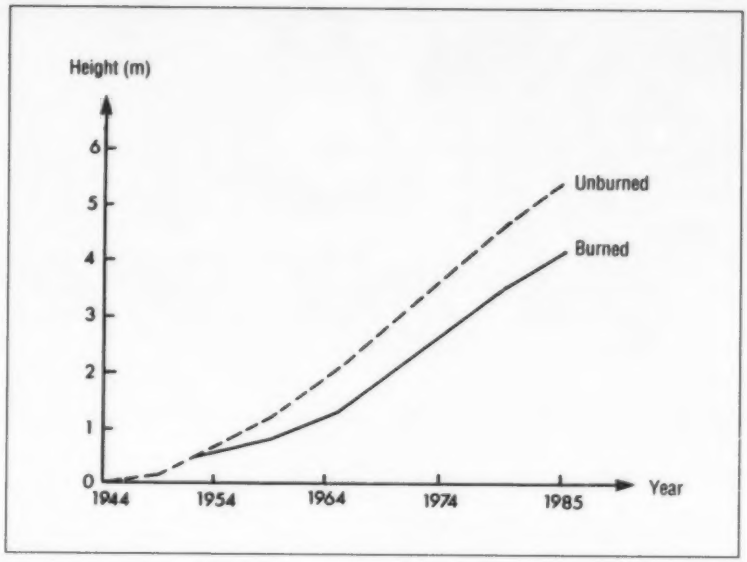


Figure 58. Height development for Norway spruce on burned and unburned sites in Ångermanland (northern Sweden) (after Kardell and Laestadius [1987]).
Spruce generally does not perform well on burned sites.

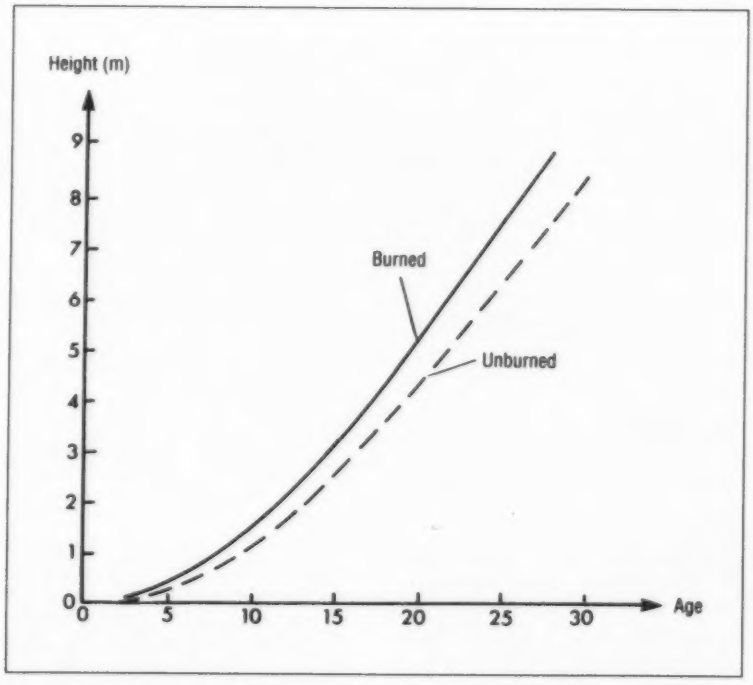


Figure 59. Height development for Scots pine on burned and unburned sites (after Andersson and Karlsson [1985]).
The early development of pine is promoted after burning.

NATURAL REGENERATION AND SOWING

CHAPTER 7

- *The role of site preparation for natural regeneration and sowing is similar to its role for planting, that is, it provides a good growth environment for the seedling. In addition, a seed requires a good germination environment. There are slight environmental differences between sowing and natural regeneration (which includes seed trees, shelterwood) because an overstory is usually present, but similarities are such that natural regeneration and sowing are included together in this section.*

Site preparation creates environments favourable for planting, sowing, and natural regeneration (ex. Tirén 1952; Hagner 1962; Hagner and deJong 1982a). On certain site types, mainly those with thin humus and good climate, adequate results can be obtained without site preparation.

Seeds begin to germinate above temperatures around 6° C; optimal germination temperatures are about 20-24° C. Good germination demands high moisture. The seed should lie on a moist substrate with a relative humidity near 100%.

As previously mentioned, site preparation increases soil temperatures but perhaps the most important function of site preparation for germination is the improvement of soil moisture. Water availability to the seed can be improved in part by pressing the soil surface to improve capillarity, and in part by covering the seed with capillary-breaking material (mulch) such as gravel, sawdust or ground-up humus to suppress surface evaporation (Hagner and Lundmark 1982). Covering the seed also provides protection from birds, rodents and insects.

How the site preparation is carried out is important. A level mineral soil surface is a good germination environment (ex. Hagner 1962; Hagner and deJong 1982a). A sharply sloping surface such as a disced trench, for example, has been shown to hinder germinant development.

Bergsten (1988) showed that germinant establishment can be doubled if the seeds are sown in depressions formed in the soil. The small depressions improve water availability and provide coverage once the depressions erode.

The use of protective shelters can greatly improve sowing results (Lähde 1979; Kinnunen 1982; Hagner 1984). Hagner

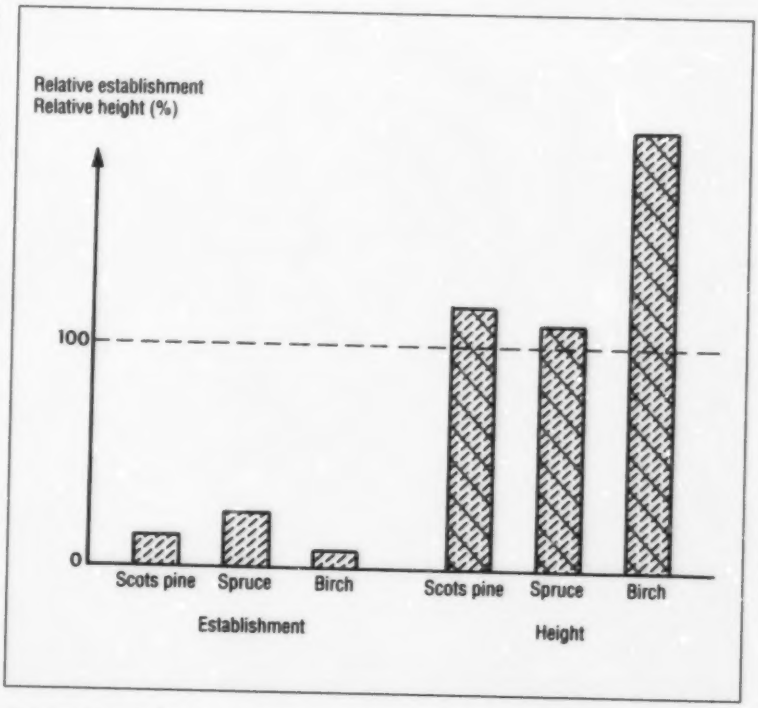


Figure 60. Relative establishment and height of seedlings in inverted humus mounds in relation to seedlings in mineral soil patches (after Hagner [1962]). (———.) Represents relative establishment and height of seedlings in mineral soil patches.

Few seeds germinate on inverted humus but these seedlings have good height growth.

and deJong (1982b) found that sowing on humus with funnel shelters (pushed into the humus) gave poorer results than with cone shelters (set on the surface).

Sowing should not be carried out on sites sensitive to frost heaving. If possible, sowing should be done on light-coloured, eluviated soil because the risk of frost heaving is less than on brown or illuviated mineral soil (Hagner and deJong 1982a).

As previously mentioned, site preparation should provide for good seedling growth following the germination phase. This means that sowing should take place, if possible, on elevated spots (mounds or berms). The problem is that these spots are dry and germination can be poor, however, the seeds that do germinate have good growth (Figure 60).

Seeds that germinate in the low-lying parts of disc trenches have significantly higher mortality than those germinating on higher parts (Bergsten 1988). Sowing spots should therefore be elevated where good germination environments are ensured by small depressions or coverage (Bergsten 1988).

As a rule, fertilization is not necessary with sowing, though there have been some individual cases of positive effects from phosphorous fertilization (Lähde and Mutka 1974).

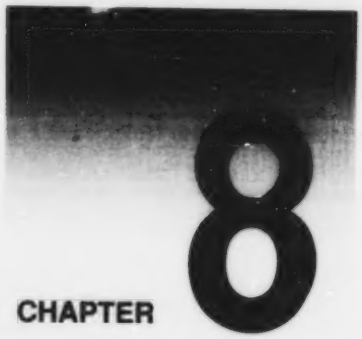
The success of natural regeneration can be affected by rapid vegetative invasion of prepared spots. The seedfall received 2-3 years following site preparation contributes most to the regeneration. The best alternative is to prepare the site when a good seed crop is expected (Skoklefald 1985).

Obviously, regeneration can be affected by the intensity of site preparation (Hagner 1962). A large area of mineral soil should be exposed for natural regeneration, and disc trenching is preferable to patch scarification for this.

A dense overstory used with shelterwood or seed tree regeneration can deter a proliferation of vegetation. This has greatest applicability in southern Sweden where a dense overstory can be necessary for good natural regeneration (Hagner 1965).

Seeding in disc trench furrows. Photo: Mats Hagner.

LONG-TERM EFFECTS OF SITE PREPARATION



- *The long-term effects of radical site preparation can be both positive and negative. Positive effects include the rapid establishment of a stand with deep root penetration and high litter production. Negative effects include rapid mineralization leading to nutrient loss.*

According to Lundmark (1988), site preparation should "create an enduring favourable soil environment for the growing stand and maintain the long-term productive capacity of the site." To obtain this, one must consider how the method of site preparation affects hydrology on the site and the rate of mineralization of humus and slash. Further considerations include the benefits from the rapid production of large amounts of litter, and the changes in the physical qualities of the soil such as looseness (bulk density) and the capacity to conduct and store heat and water. "Harsh" site preparation can be detrimental to the long-term site productivity of some site types, while complete or deep plowing may provide long-term ameliorating effects and increases in productivity on other site types.

German studies from the 1940's showed that raw humus soil types could be converted to Mull soil forms (Wittich 1942, 1957; Rehfuess 1978). This was done by using a combination of "harsh" site preparation (deep plowing), fertilization (phosphorous), liming, and cultivation of nitrogen-fixing plants (Rehfuess 1978). The results from this system of site preparation are consistently positive.

As previously mentioned, deep plowing is used in Germany, Scotland, and Ireland for breaking up unfavourable soil profiles. Deep plowing enhances root penetration and increases the rooting volume of the soil. This has great significance for the stand's water and nutrient uptake (Hochtanner and Seitschek 1964; Hetsch *et al.* 1981). Benefits of increased rooting volume are also discussed by Kohh (1970).

Deep plowing also often improves soil water relations by improving infiltration and preserving moisture in the buried humus material during dry periods (Buchholz and Neumann 1964) (Table 5).

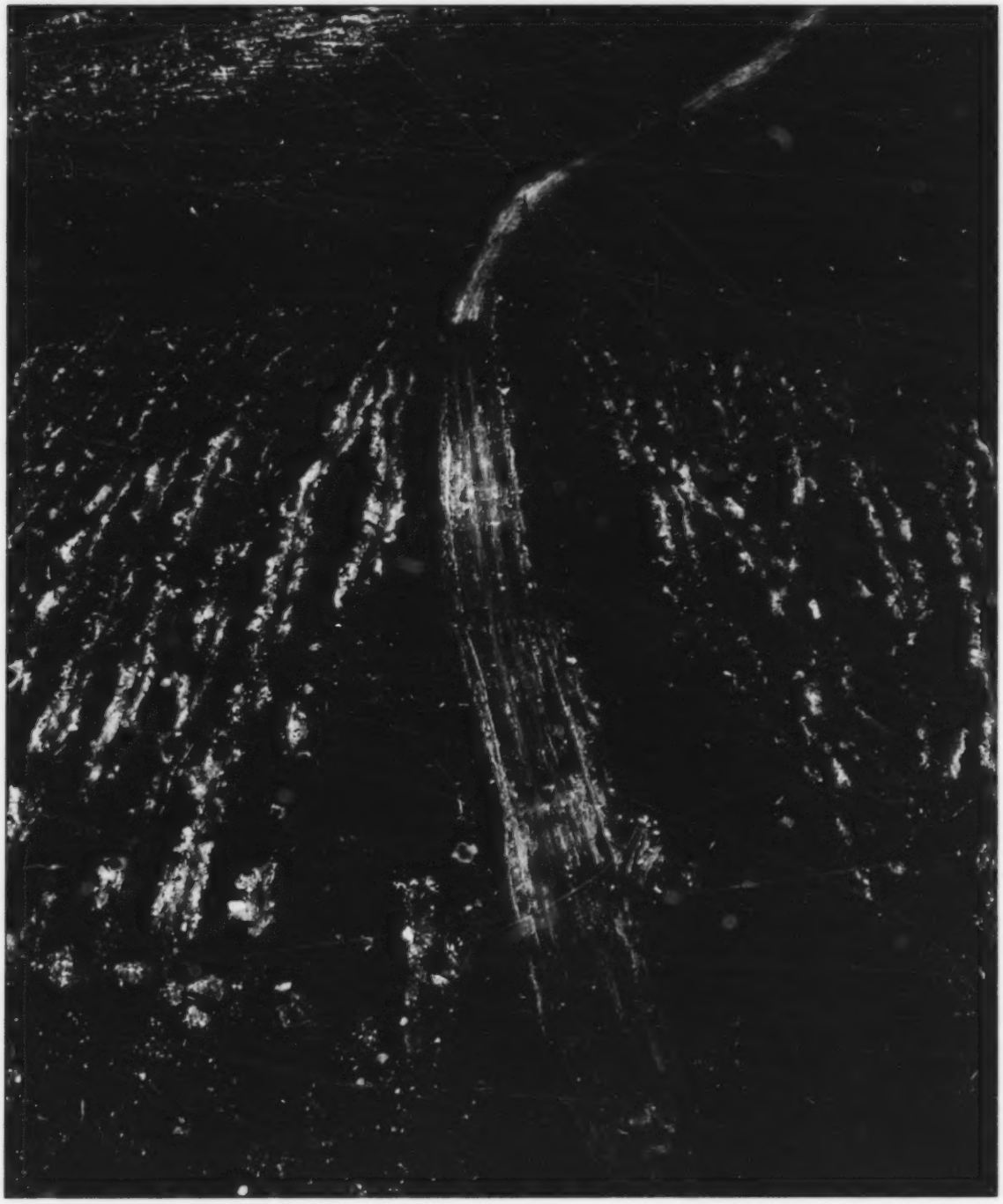
Deep plowing is also used in agriculture. The effect of increased plowing depth is often beneficial, although there are soil types where detrimental effects can be expected (Unger 1979; Kritz 1987).

TABLE 5. The difference in available plant water (mm) between deep-plowed (70 cm) and disc-trenched soils of different depths. (Deep plowed (mm) minus disc trenched (mm)).

Depth	Wet soil	Dry soil
0-10	-2.8	-0.1
11-20	-0.6	1.2
21-30	1.3	2.0
31-40	2.1	2.4
41-50	3.7	3.5
51-60	5.2	4.8
61-70	6.5	6.3

The motive behind plowing in northern Sweden and Finland is primarily to establish a stand rather than to improve the site productivity. As early as 1926, Wittich (Rehfuess 1978) showed that plowing resulted in a significant loss in humus material and nitrogen compared with that in uncultivated control areas. Later studies showed even greater losses with the mixing of humus and mineral soil, such as occurred with roto-tilling (Burschel *et al.* 1977). Swedish studies have demonstrated increased rates of mineralization under plow- and disc-trench berms (e.g., Rosén and Lundmark-Thelin 1986). The amount of mineralized nutrients depends on the area disturbed by the preparation treatment. Several Swedish researchers warn against harsh soil treatments such as plowing and disc trenching, which can impair future nutrient regimes (Rosén and Lundmark-Thelin 1986; Johansson 1987; Lundmark 1988). At the same time, Lundmark (1988) indicates that sites with unfavourable humus forms in areas of cold climate should have the rate of mineralization increased beyond that which normally occurs following clearcutting.

Long-term productivity may not, however, always be impaired by harsh treatments. Kardell (1987) compared growth



Cut-over plowing. Photo: Leif Öster.

on sites following burning, whole-tree utilization, and complete removal of humus on a gravel pit. He did not find large growth differences on Scots pine productivity.

Troedsson and Utbult (1972, 1974) warned that drainage from plowing can degenerate site productivity. However, experimental results have not affirmed that increased runoff following plowing is a problem (Lundmark-Thelin, pers. comm.)

8.1 How Strong Is the Proof?

How strong is the proof that "harsh" site preparation can reduce long-term site productivity? So far, there are not any plowing or disc trenching experiments in Fennoscandia sufficiently old from which any firm conclusions can be drawn. To date, most plowing experiments have shown consistently high production (ex. Pohtila and Valkonen 1985; Mälkönen 1986; Örlander 1987). However, Lundmark (1977, 1988) has analyzed two "spade-inversion" experiments on poor heath sites in northern Sweden (Routiroova and Andersfors) and found reduced growth after mixing of humus and mineral soil. Initial growth was more rapid after mixing, however, the relative growth rate decreased over time. At Routiroova the heights of the greatest diameter trees are similar in the "spade-inverted" and untreated plots (6.2 and 6.1 m, respectively) at 50 years of age. The Routiroova and Andersfors experiments lack replication and are further disadvantaged by the removal of slash and a dependence on natural regeneration (Holmbäck and Malmström 1947).

A plowing experiment on a northern pine heath at Anundsjö (Kohh 1970; Bengtsson and Petré 1985) had the highest productivity in completely plowed plots compared with that in burned and untreated plots (Figure 61).

An experiment in Scotland (Wilson and Pyatt 1984) showed that deep plowing gave the best growth results during the initial 10-year period, poor growth from 20 to 30 years, and then good growth after 30 years of age.

Where is "harsh" site preparation justified?

- On sites where the soil profile is poor (e.g., hardpans) or in old fields (compacted).
- On sites where mineralization of nutrients is desirable. These are mainly in cold climate areas with an "inactive" humus layer.
- On difficult-to-regenerate sites, such as those which are frost prone, or where risk of failure with other methods is high.

Where should "harsh" site preparation be avoided?

- On poor site types with thin humus layers, dry or coarse-texture soils.
- On sites with sensitive nature values or multiple uses such as recreation and wildlife.

In conclusion, "harsh" site preparation should be limited to areas where forest production is a high priority. Where possible, establishment problems should be overcome by milder treatments such as mounding, or mounding and ditching.

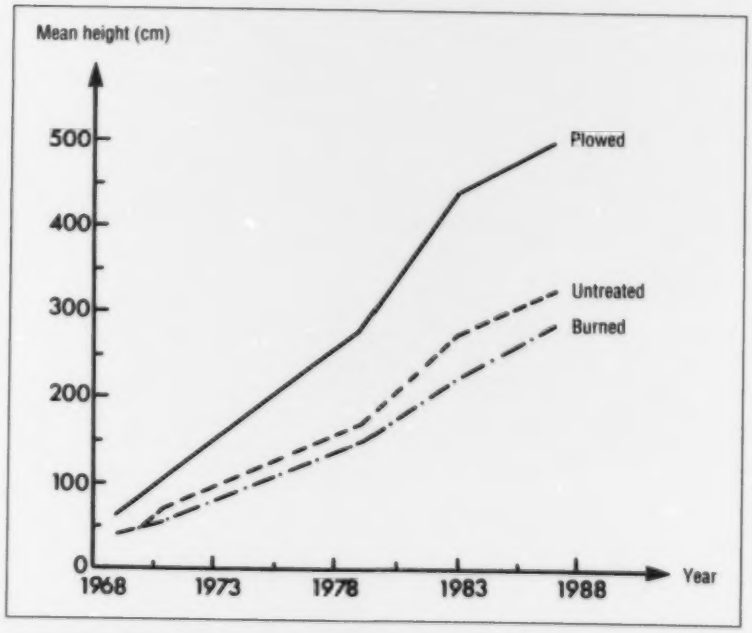


Figure 61. Height development of Scots pine following complete plowing, prescribed burning, and control treatments. Dry, lichen type heath site at Anundsjö (northern Sweden) (after Örlander, Hallsby and Sundkvist [in prep.]).

Complete plowing has shown the best height and volume development in this experiment, despite some nutrient losses.

In deep-plowing the total area is treated to a depth greater than that achieved with a standard farm plow. Photo: Göran Örlander.

LITERATURE CITED

Adelsköld, G. and G. Örlander. [1989]. Val av planteringspunkt (Choice of planting spot). Skogsarbeten Resultat. 8.

Andersson, S. 1973. Vattnet i jorden (Water in the soil). Lantmannen 22.

Andersson, S.O. 1976. En studie av miljön's betydelse för granplantors tillväxt på ett hygge i östra Svealand (A study on the significance of environment on spruce seedlings' growth on a clearcut in eastern Svealand). Sver. Lantbruksuniv., Inst. f. Skogsskötsel, Rapport 8.

Andersson, B. and S. Karlsson. 1981. Hyggesbränningens effekt på tallens produktion (The effect of prescribed burning on productivity of Scots pine). Undergraduate thesis. Sver. Lantbruksuniv., Inst. f. Skogsskötsel, Umeå, Sweden.

Axelsson, M. 1987. Direktplantering - en möjlighet? (Direct planting: a possibility?). Sver. Skogsvårdsförb. Tidskr. 5:23-26.

Bengtsson, H. and E. Petré. 1985. Markbehandlingens påverkan på plantetableringen och den långsiktiga skogsproduktionen (The influence of site preparation on seedling establishment and long-term productivity). Undergraduate thesis. Sver. Lantbruksuniv., Inst. f. Skogsskötsel, Umeå, Sweden.

Berg, S., J. Bäcke, and C. Jonsson. 1981. Markberedningsförsök i Kosta och Bräcke (Site preparation experiments in Kosta and Bräcke). Skogsarbeten Redogörelse 2.

Bergman, F. 1980. Skogsproduktion på våtmark - Beståndsanläggning (Forest productivity on wetlands: stand establishment). Skogsarbeten Redogörelse 3, pp. 49-55.

Bergsten, U. [1988]. Pyramidal indentations as a microsite preparation for direct seeding of *Pinus sylvestris*. Scand. J. For. Res. 3, 493-503.

Björkdahl, G. and M. Sandewall. 1977. Plantutveckling efter hyggegesplogning (Seedling development after plowing). Undergraduate thesis. Sver. Lantbruksuniv., Inst. f. Skogsskötsel, Umeå, Sweden.

Braekke, F. 1972. Varmehusholdining og mikroklima på ulike myrtyper (Temperature regimes and microclimate on different bog types). Medd. f. det Norske Skogsf. 119.

Buchholz, F. and E. Neumann. 1964. Der Einfluss der Bodenbearbeitung und Dungung auf den Wasserhaushalt und die Durchwurzelung sandiger Waldböden Brandenburgs. Albrecht-Thaer-Archiv. 8:525-536.

Burgtorf, H. 1968. Exempel på kaliumbrist hos gran, planterad på åkermark (Examples of potassium deficiencies in spruce planted on fields). Sver. Lantbruksuniv., Inst. f. Växtekologi, Rapporter och Uppsatser 7.

Burschel, P., R. Eder, D. Kantarci, and K.E. Rehfuess. 1977. Wirkungen verschiedener Bodenbearbeitungsverfahren auf Wachstum, Phytomasseakkumulation und Nährelementvorräte junger Kiefernwaldökosysteme (*Pinus sylv.* L.). Forstw. Cbl. 96:321-338.

Buss, K. 1932. Bra exempel på skogskultur (A good example of forest cultivation). (Translated from Russian to Swedish.) Swedish Cellulose Company, Stencil. Meza dzive, 1-3.

Bäcke, J., M. Larsson, J.-E. Lundmark, and G. Örlander. 1986. Ståndortsanpassad markberedning (In Swedish with English summary: Site adapted scarification). Skogsarbeten Redogörelse 3.

Bäckström, P.-O. 1986. Utveckling och forskning om skogsföryngring i Sverige eftr 1950 (Development and research in forest regeneration in Sweden after 1950). Norsk Inst. f. Skogsforsk. Meddelelser 39:330-341.

Bärring, U. 1962. Plantering på inägojord (Planting on derelict fields). Skogen 10:1-4.

_____. 1965. Om fläckupptagningens betydelse och några andra problem vid plantering av tall och gran (In Swedish with English summary: On the significance of patch scarification and other problems with planting pine and spruce). Stud. For. Suec. 24.

_____. 1967. Studier av metoder för plantering av gran och tall på åkermark i södra och mellersta Sverige (In Swedish with English summary: Studies of methods for planting spruce and pine on old fields in southern and central Sweden). Stud. For. Suec. 50.

Cooper, A.J. 1973. Root temperature and plant growth. Commonwealth Agricultural

Bureaux, Research Review, No 4.

Davies, R.J. 1987. Trees and weeds. For. Commission Handb. 2.

Dobbs, R.C. and R.G. McMinn. 1977. Effects of scalping on soil temperature and growth of white spruce seedlings. *In* Proc. 6th B.C. Soil Science Workshop. T. Black *et al.* (editors). B.C. Min. Agric., pp. 66-73.

Draper, D., W. Binder, R. Fahlman, and D. Spittlehouse. 1985. Post-planting ecophysiology of interior spruce. Paper presented at "Interior Spruce Seedling Performance: State of the Art", Northern Silv. Committee Seminar, Prince George, B.C., Feb. 5-6, 1985.

Eidman, H.H. 1986. Skall insekterna få härja - eller vad skall vi göra? (Shall the insects plague: or what shall we do?). Sver. Skogsvårdsförb. Tidskr. 1:49-53.

Eriksson, B. 1986. Nederbörds-och humiditetsklimatet i Sverige under vegetationsperioden (In Swedish with English summary: Precipitation and humidity climate in Sweden during the vegetation period). SMHI Rapport 46.

Eriksson, J. 1982. Markpackning och rotmiljö (Soil compaction and the root environment). Sver. Lantbruksuniv., Inst. f. Markvetenskap, Rapport 126.

Ferm, A. and P. Sepponen. 1981. Development of ploughed tracks and vegetation on reforestation areas in Finnish Lapland during a period of 10 years (In Finnish with English summary). Folia Forstalia 493.

Friej, J. and G. Örlander. 1987. Högläggning på mineraljord eller humustäcke - en försöksserie med olika trädslag, planttyper och planteringstidpunkt (Mounding on mineral soil or humus - a series of experiments with different species, stock types, and planting times). Sver. Lantbruksuniv., Inst. f. Skogsskötsel, Arbetsrapporter 19.

Fries, C. 1984. Den frösådda björkens invandring på hygget (Invasion of seed origin birch on clearcuts). Sver. Skogsvårdsförb. Tidskr. 3-4:35-49.

Graber, R.E. 1971. Frostheaving... seedling losses can be reduced. Tree Planters Notes 22:24-28.

Granström, A. 1985. Fröbanken i svensk skogsmark (The seedbank in Swedish forest soils). Sver. Lantbruksuniv., Skogsfakta 7.

Hagner, M. 1984. Överlevnad och tillväxt under nio år hos konsådd tall (Survival and growth over 9 years with cone shelter sown pine). Sver. Skogsvårdsförb. Tidskr. 5:5-19.

_____. 1985. The influence of microenvironment upon survival and growth in *Pinus sylvestris*. IUFRO Working Party S1.05-12, Gällivare, Sweden.

Hagner, M. and A. deJong. 1982a. Radsådd efter harvning (Row seeding after disc trenching). Umeå Universitet, Inst. f. Skoglig Produktionslära, Rapport 127.

_____. 1982b. Trattsådd (Funnel seed cone). Umeå Universitet, Inst. f. Skoglig Produktionslära, Rapport 122.

Hagner, M. and B. Hansson. 1987. Överlevnad och tillväxt hos tallplantor med insekts- och uttorkningsskydd planterade direkt i humustäcket på nyavverkade hyggen (Survival and growth of pine seedlings with insect and desiccation protection planted directly in humus on recent clearcuts). Umeå Universitet, Inst. f. Skoglig Produktionslära, Rapport 138.

Hagner, M. and G. Lindberg. 1984. PUM förbättrar överlevnaden hos plantor satta i humustäcket (PUM improves survival of seedlings planted in humus). Umeå Universitet, Inst. f. Skoglig Produktionslära, Rapport 136.

Hagner, M. and A. Lundmark. 1982. Täckning med humus vid radsådd (Row sowing and covering with humus). Umeå Universitet, Inst. f. Skoglig Produktionslära, Rapport 128.

Hagner, S. 1962. Naturlig föryngring under skärm (Natural regeneration under shelter). Ph.D. thesis. Skogshögskolan, Stockholm, Sweden.

_____. 1965. Om fröproduktion, fröträdsval och plantuppslag i försök med naturlig föryngring (On seed production, selection of seed-trees, and establishment experiments with natural regeneration). Stud. For. Suec. 27.

Hannerz, M. 1987. Redovisning av projektet "Beskogning av öppna skogliga våtmarker" (Report on the project "Forestation of open forest wetlands.") Sver. Lantbruksuniv., Inst. f. Skogsskötsel, Stencil.

Heidmann, L.G. 1976. Frost heaving of tree seedlings. U.S. Dep. Agric. For. Serv., Gen. Tech. Rep. RM-21.

Heidmann, L.G. and D.B. Troud. 1976. Controlling frost heaving on ponderosa pine seedlings in Arizona. U.S. Dep. Agric. For. Serv., Gen. Tech. Rep. RM-172.

Heikkilä, R. 1981. Damage in Scots pine plantations in northern Finland (In Finnish with

English summary). Folia Forestalia 497.

Hetsch, W., W. Kramer, and W. Wessels. 1981. Bodenkundliche und waldbauliche Auswirkungen einer kombinierten Meliorationsmassnahme im Forstamt Syke. Der Forst- und Holzwirt. 36:21, 548-554.

Hillell, D. 1982. Introduction to soil physics. Academic Press, New York, N.Y.

Hochtanner, G. and O. Seitschek. 1964. Wuchsleistungen von Kiefernbeständen auf Meliorierungsflächen nach den Bodenwöhrer Verfahren. Forstw. Cbl. 83.

Holmbäck, B. and C. Malmström. 1947. Några markförbättringsförsök på nordsvenska tallhedar (Some site preparation experiments on northern Swedish pine heaths). Meddel. från Statens Skogsforskningsinstitut 36.

Hultén, H. 1976. Rotade plantor och markberedning (Containerized seedlings and site preparation). Skogsarbeten Redogörelse 6, pp. 37-40.

Hunt, J.A. and R.G. McMinn. 1988. Site preparation and forest regeneration in Sweden and Finland: implications for technology transfer. For. Can. and B.C. Min. For., FRDA Report 031.

Huuri, O. 1980. Effect of milled rock phosphate root coating on the initial development of Scots pine and Norway spruce transplants on mineral soils. Folia Forestalia 445, 1-25.

Hägglund, B. and L.G. Svensson. 1982. Ståndortsförhållanden på skogsmark och myr i Sverige (The relationship between productive forest land and swamps in Sweden). Sver. Lantbruksuniv., Inst. f. Skogstaxering, Rapport 35.

Ingelög, T. 1974. Vegetationsförändringar efter förnyelseingrepp (Changes in vegetation following regeneration treatments). Sver. Skogsvårdsförb. Tidskr. 1:91-96.

Jarvis, P.G. 1980. Stomatal response to water stress in conifers. *In* Adaption of plants to water and high temperature stress. N. Turner and P. Kramer (editors). Blackwell, Oxford, pp. 105-122.

Johansson, M.-B. 1987. Radikal markberedning - olämpligt sätt att utnyttja kväveförrådet i avverkningsresterna (Radical site preparation - an unsuitable way to utilize the nitrogen capital in logging residue). Sver. Skogsvårdsförb. Tidskr. 2:35-41.

Kardell, L. 1987. Kan naturen undvara ris och stubbar? (Can nature do without stumps and slash?). Sver. Skogsvårdsförb. Tidskr. 10:9-27.

Kardell, L. and L. Laestadius. 1987. Granens produktion efter 1943 års hyggesbränning på övrahygget i Ångermanland (Spruce productivity after the 1943 burn in Ångermanland). Sver. Skogsvårdsförb. Tidskr. 3:19-29.

Kaunisto, S. and J. Päivinen. 1985. Forest regeneration and afforestation on drained peatland: a literature review (In Finnish with English summary). Folia Forestalia 625.

Kauppila, A. and E. Lähde. 1975. On the effects of soil treatments on forest soil properties in North Finland (In Finnish with English summary). Folia Forestalia 230.

Kinnunen, K. 1982. Scots pine sowing on barren soils in western Finland (In Finnish with English summary). Folia Forestalia 531.

Kohh, E. 1970. Bidrag till frågan om skogmarksplöjning. (Contribution to the question of plowing). Sver. Skogsvårdsförb. Tidskr. 2:75-106.

Krajina, V. 1969. Ecology of forest trees in B.C. Ecology of Western North America 1(2):1-147.

Kritz, G. 1987. Hur djupt bör man plöja (How deep should one plow?). Sver. Lantbruksuniv., Fakta, mark-växter 1.

Kubin, E. and J. Poikolainen. 1982. Snow and frost conditions in uncut forest and open clear-cut ares prepared in various ways (In Finnish with English summary). Folia Forestalia 518.

Körlen, R. and L. Kardell. 1987. Tallens och granens produktion efter 1753 års skogsbrand i Umgransele (The productivity of pine and spruce after the 1753 burn in Umgransele). Sver. Skogsvårdsförb. Tidskr. 4:15-28.

Leijon, B. 1985. Skogens tillväxt efter helträdsutnyttjande (Forest growth following whole-tree utilization). Sver. Lantbruksuniv., Skogsfakta Konferens 7, pp. 122-125.

Leikola, M. 1976. Soil tilling and weed control in afforestation of abandoned fields (In Finnish with English summary). Comm. Inst. For. Fenn. 88(3):1-101.

Lekander, B. and V. Söderström. 1969. Studier över snytbaggengrepp på barrträdsplantor (Studies on pine weevil attacks on conifer seedlings). Sver. Skogsvårdsförb. Tidskr. 6-7:351-383.

Leyton, L. and L. Rousseau. 1958. Root growth of tree seedlings in relation to aeration. *In* Physiology of forest trees. K.V. Thiman (editor). New York, N.Y.

Lindell, M. 1982. Granens tillväxtstart och etablering - barrmassans anpassining till

olika ljusförhållanden och reaktioner efter utplantering (The establishment and growth of spruce: adaptation of needles to different light regimes and reactions after planting). Sver. Lantbruksuniv., Inst. f. Skogsproduktion, Stencil 15.

Lindman, B. and S. Nordström. 1964. Grönrisplantering (Green slash planting). Undergraduate thesis. Sver. Lantbruksuniv., Inst. f. Skogsskötsel, Umeå, Sweden.

Lindström, A., C. Hellqvist, B. Gyldberg, B. Långström, and A. Mattson. 1986. Field performance of a protective collar against damage by Hylobius abietis. Scand. J. For. Res. 1:3-15.

Lundmark, J.-E. 1977. Marken som del av det skogliga ekosystemet. (The soil as a part of the forest ecosystem). Sver. Skogsvårdsförb. Tidskr. 2:108-1.

_____. 1986. Skogsmarkens ekologi, del I, grunder (The forest soil's ecology, part I, basics). Skogsstyrelsen, Jönköping.

_____. 1988. Skogsmarkens ekologi, del II, tillämpning (The forest soil's ecology, part II, application). Skogsstyrelsen, Jönköping.

Lundmark, T. 1982. Effekten av markberedning på nattemperaturen i luft (The effect of site preparation on night air temperatures). Undergraduate thesis. Sver. Lantbruksuniv., Inst. f. Ståndortslära, Umeå, Sweden.

_____. 1985. Temperaturens påverken på plantor (Temperature's effect on seedlings). Sver. Lantbruksuniv., Skogsfakta Konferens 7:51-54.

_____. 1987. Föryngring på dikade marker. III - Föryngring på torvmarker (Regeneration on ditched sites. III - regeneration on peatlands). K. Skogs- o. Lantbr. Tidskr. 126:283-296.

Lyngfelt, B. and U. Nilsson. 1985. Ståndortsegenskapernas variation och dennas inverkan på lönsamheten i en intensivare skogsvårdsplanering (The qualities of site types and their influence on profitability in intensive silviculture). Undergraduate thesis. Sver. Lantbruksuniv., Inst. f. Skogsskötsel, Umeå, Sweden.

Lähde, E. 1978. Effect of soil treatment on physical properties of the soil and on development of Scots pine and Norway spruce seedlings (In Finnish with English summary). Comm. Inst. For. Fenn. 94(5).

_____. 1979. Shelter and open sowing of Scots pine, Norway spruce and Siberian larch on the shoulder and tilt of ploughing (In Finnish with English summary). Comm. Inst. For. Fenn. 97(4).

_____. 1984. Voimaperäiset muokkaukset uhka metsäluonnolle. Lounais-Hämeen Lounto. 70:69-71.

Lähde, E., S. Manninen, and M. Tervonen. 1981. The effect of drainage and cultivation on soil physical properties and the development of conifer seedlings (In Finnish with English summary). Comm. Inst. For. Fenn. 98(7).

Lähde, E. and K. Mutka. 1974. The structure of root sytems and development of volunteer and planted Norway spruce transplants in Northern Finland (In Finnish with English summary). Comm. Inst. For. Fenn. 83(3).

McMinn, R.G. 1985. Mechanical site preparation and spruce performance. Presented at "Interior Spruce Seedling Performance: State of the Art", Northern Silv. Committee Seminar, Prince George, B.C.

Minore, D., C.E. Smith, and R.F. Woollard. 1969. Effects of high soil density on seedling root growth of seven northwestern tree species. U.S. Dep. Agric. For. Serv., NW For. Range Exp. Sta., Res. Note PNW-112.

Mitchell, M.L. 1981. Effects of soil compaction on root development and seedling establishment. N. Carolina Agr. Res. Serv. Paper 81-1040.

Mutka, K. and E. Lähde. 1977. Effect of soil treatment, liming, and phosphate fertilzation on initial development of bare rooted scots pine transplants. Comm. Inst. For. Fenn. 91(3).

Mälkönen, E. 1972. Some aspects concerning cultivation of forest soil (In Finnish with English summary). Folia Forestalia 137.

_____. 1986. A review of soil preparation in Finland. IUFRO WorkingParty S1.05-12. Grande Prairie, Alta. - Dawson Creek, B.C.

Nilsson, T. 1985. Studie över tillämpade föryngringsmetoder på Oskarshamns revirs brandfält (Study of regeneration methods on burns in the Oskarshamn area). Sver. Lantbruksuniv., Inst. f. Skogsskötsel, Arbetsrapporter 5.

Odin, H., B. Eriksson, and K. Perttu. 1983. Temperature climate maps for Swedish Forestry (In Swedish with English summary). Sver. Lantbruksuniv., Rapporter i Skogsekologi och Skoglig Marklära 45.

Ovsjankins, V. and T. Kaninskaja. 1960. Plantering av tall i rabatter (Planting of pine in mounds). (Translated from Russian to

Swedish.) Swedish Cellulose Company, Stencil. Mezsaimniecibas jautajumi, Riga.

Palmgren, K. 1984. Microbiological changes in forest soil following soil preparation and liming (In Finnish with English summary). Folia Forestalia 603.

Palo, I. 1986. Björkfröets groning och björkplantors etablering - Literaturstudie (The germination of birch seed and establishment of birch seedlings: a literature study). Sver. Lantbruksuniv., Inst. f. Skogsskötsel, Arbetsrapporter 11.

Pohtila, E. 1977. Reforestion of ploughed sites in Finnish Lapland. Comm. Inst. For. Fenn. 91(4).

Pohtila, E. and T. Pohjola. 1983. Results from the reforestation experiment on ploughed sites established in Finnish Lapland during 1970-1972 (In Finnish with English summary). Silva Fenn. 17(3):201-224.

Pohtila, E. and S. Valkonen. 1985. Development and condition of artificially regenerated pine and spruce sapling stands in the privately owned forests of Finnish Lapland (In Finnish with English summary). Folia Forestalia 631.

Päivänen, J. 1973. Hydraulic conductivity and water retention in peat soils. Acta For. Fenn. 129.

Rehfuess, K. 1978. Aufgaben und Leitlinien waldbodenkundlicher Forschung. Forstarchiv 49(5):85-89.

Rigner, P.O. and J. Sundin. 1985. Hyggesplogningens inverkan på minimitemperaturen nära marken (The effect of plowing on minimum temperatures near the ground). Undergraduate thesis. Sver. Lantbruksuniv., Inst. f. Skogsskötsel, Umeå, Sweden.

Ritari, A. and E. Lähde. 1978. Effect of site preparation on physical properties of the soil in a thick-humus spruce stand. Comm. Inst. For. Fenn. 92(7).

Romell, L.G. 1922. Luftväxlingen i marken som ekologisk faktor (Gas exchange in the soil as an ecological factor). Meddel. från Statens Skogsförsöksanstalt 19.

Rosén, K. and A. Lundmark-Thelin. 1986. Hyggesbruket ooh markvården (Clearcutting and soil conservation). Sver. Lantbruksuniv., Skogsfakta Konferens 9:42-49.

Ross, S.M. and D.C. Malcolm. 1982. Effects of intensive forestry ploughing practices on an upland heath soil in south east Scotland. Forestry. 55(2):155-171.

Rosvall-Åhnebrink, G. 1985. Invintring av plantor för höstplantering eller vinterlagring (Hardening seedlings for fall planting or winter storage). Sver. Lantbruksuniv., Skogsfakta, Konferens 7:3-37.

Russell, R.S. 1977. Plant root systems. McGraw-Hill, New York, N.Y.

Sachs, J. 1860. Krystallbildungen bei dem Gefrieren und Veränderung der Zellhäute bei dem Aufthauen Saftiger Pflanzentheile. Ber. Über die Verhandl. d. Königl. Sächsishen Ges D. Wissenscaften, Math - phys. Classe 12:1-50.

Sahlén, K. 1975. Förekomsten av lövträdsplantor på hyggesplogad mark (The occurrence of broadleaved seedlings on plowed sites). Undergraduate thesis. Sver. Lantbruksuniv., Inst. f. Skogsskötsel, Umeå, Sweden.

Sakai, A. and W. Larcher. 1987. Frost survival of plants. Springer-Verlag, Berlin, Ecological studies 62.

Sands, R. and G.D. Bowen. 1978. Compaction of sandy soils in radiata forests. II Effects of compaction on root configuration and growth of radiata pine seedlings. Aust. For. Res. 8:163-170.

Savill, P.S. 1976. The effects of drainage and ploughing of surface water gleys on rooting and windthrow of sitka spruce in northern Ireland. Forestry 49(2):133-140.

Sims, H.P. 1975. Temperature and moisture conditions on a plowed jack pine strip cut in south-eastern Manitoba. Can. J. For. Res. 5:541-545.

Sinko, M. and E. Jakabbfy. 1972. Några resultat vid orienterande försök med markplöjning och djupluckring av mark före plantering (Some orienting studies on plowing and deep loosening before planting). Sver. Skogsvårdsförb. Tidskr. 2:137-142.

Sirén, G. 1973. Markberedning -ett nödvändigt ont (Site preparation - a necessary evil). Sveriges Nature, Årsbok 1973:97-106.

Skogsstyrelsen. 1986. Återväxttaxeringarna 1984 och 1985 (Regeneration surveys 1984 and 1985). Meddelande från Skogsstyrelsen 5.

———. 1989. Statistical yearbook of forestry 1988. National Board of Forestry, Jönköping, Sweden.

Skoklefald, S. 1985. Natural regeneration of Norway spruce and Scots pine in Norway. IUFRO Working Party S1.05-12, Gällivare, Sweden.

Smolander, H., P.K. Räsänen, and J. Kostamo. 1981. Effect of soil compaction on transpiration and height increment of planted Scots pine seedlings. Silva Fennica 15:256-266.

Sokolovskaya, N.A., I.B. Revut, I.A. Markova, and I.R. Shevlyakov. 1977. The role of soil density in forest regeneration (In Russian

with English summary). Lesovedenie 2:44-51.

Squire, R.O., G.C. Marks, and F.G. Craig. 1978. Root development in a *Pinus radiata* plantation in relation to site index, fertilizing and soil bulk density. Aust. For. Res 8:103-114.

Strand, M. and T. Lundmark. 1987. Effects of low night temperature and light on chlorophyll fluorescence of field-grown seedlings of Scots pine. Tree Physiol. 3:211-224.

Strahler, A.N. 1975. Physical geography. John Wiley and Sons, New York, N.Y.

Strathers, R. 1989. Summer frost in young forest plantations. For. Can. and B.C. Min. For., FRDA Report 073.

Ståål, E. and Y. Franzon. 1961. Plantering i grönt ris på nya hyggen (Planting in green slash on a recent clearcut). Skogen 1961.

Sundkvist, H. 1988. Rotutveckling och stabilitet hos contorta och tall planterade på plogade hyggen (Root development and stability of lodgepole and Scots pine on a plowed clearcut). Undergraduate thesis. Sver. Lantbruksuniv., Inst. f. Skogsskötsel, Umeå, Sweden.

Söderström, V. 1970. Mätning av markfuktighet (Measurement of soil moisture). Skogen 1970:256-257.

_____. 1974a. Om syretillgången på färska moränhyggen (On oxygen availability on fresh moraine clearcuts). Sver. Skogsvårdsförb. Tidskr. 1:327-336.

_____. 1974b. Markberedning (In Swedish with English summary: Site preparation). Sver. Skogsvårdsförb. Tidskr. 1:157-166.

_____. 1975. Ekologiska verkningar av hyggesplogning (In Swedish with English summary: Ecological effects of plowing mineral soil before planting on clearfelled areas). Sver. Skogsvårdsförb. Tidskr. 5:443-472.

_____. 1976a. Analys av markberedningseffekterna vid plantering på några färska hyggen (In Swedish with English summary: Analysis of the effects of scarification before planting conifers on some newly clearfelled areas in Sweden). Sver. Skogsvårdsförb. Tidskr. 2-3:59-333.

_____. 1976b. Markvärme-en minimifaktor vid plantering (Soil temperature: a minimum factor when planting). Skogsarbeten Redogörelse 6, pp. 16-22.

_____. 1977. Markberedningens inverkan på markegenskaperna (The influence of site preparation on soil qualities). Sver. Skogsvårdsförb. Tidskr. 2-3:225-232.

Söderström, V., J. Bäcke, R. Byfalk, and C. Jonsson. 1978. Jämförelse mellan plantering i jordrabatter och efter andra markberedningsmetoder (In Swedish with English summary: Comparison between planting in mineral heaps and some other soil treatment methods). Skogshögskolan, Inst. f. Skogsskötsel, Rapp. o. Upps. 11.

Söderström, V., C. Jonsson, and R. Byfalk. 1979. Optimal fläckstorlek vid markberedning för plantering -ett principförsök (Optimal site preparation patch size for planting). Skogshögskolan, Inst. f. Skogsskötsel, Interna Rapporter 2.

Tikkanen, E. 1987. Onormal utveckling hos tallplantor på hyggesplogade områden i Finland (Abnormal development of pine seedlings in plowed areas in Finland). Sver. Skogsvårdsförb. Tidskr. 5-6:33-35.

Tirén, L. 1952. Om försök med sådd av tall och granfrö i Norrland (Experiments with sowing pine and spruce in Norrland). Meddel. från Statens Skogsforskn. Inst. 41.

Troedsson, T. and N. Nykvist. 1973. Marklära och markvård (Soil science and soil conservation). Almqvist and Wiksell, Stockholm.

Troedsson, T. and K. Utbult. 1972. Hyggesplöjning från hydrologisk synpunkt (In Swedish with English summary: Plowing from a hydrological viewpoint). Sver. Skogsvårdsförb. Tidskr. 5:477-486.

_____. 1974. Hydrologiska och markfysikaliska förändringar genom kalhuggning (In Swedish with English summary: Hydrological and physical soil changes through clear cutting). Sver. Skogsvårdsförb. Tidskr. 1:66-74.

Uggla, E. 1973. Fire ecology in Swedish forests. Tall Timbers Fire Ecology Conf. 13:171-190.

Unger, P.W. 1979. Effects of deep tillage and profile modification on soil properties, root growth, and crop yields in the United States and Canada. Geoderma 22:275-295.

von Mohl, H. 1860. Ueber die anatomischen veränderungen des blattgelenkes welche das abfallen der blätter herbeiführen. Bot. Zeitg. 18:9-17.

Voss-Lagerlund, K. 1976. The effects of soil preparation on the bacterial population in forest soil. Comm. Inst. For. Fenn. 86(7).

Wahlgren, A. 1914. Skogsskötsel (Silviculture). Norstedts förlag, Stockholm.

Wibeck, E. 1920. Om olika skogsodlingsmetoders förhållande till uppfrysningsfaran i Norrland (Regeneration methods and frost

heaving) Meddel. från Statens Skogsförsöksanstalt 17, 329-347.

Wilson, K. and D.G. Pyatt. 1984. An experiment in intensive cultivation of an upland heath. Forestry. 57(2):117-141.

Wittich, W. 1942. Aktivierung von Rohhumus extrem ungunstiger Beschaffenheit. Zeitschr. Forstiu. Jagdwesen 74:241-271.

Ångström, A. 1974. Sveriges klimat (Sweden's climate). AB Kartografisk Institutet, Stockholm.

Örlander, G. 1984. Some aspects of water relations in planted seedlings of *Pinus sylvestris*. Ph.D. thesis. Swed. Univ. Agric. Sci., Dep. Silviculture, Umeå, Sweden.

_____. 1985. Plantetablering - en fråga om vattenupptagning (Seedling establishment: a question of water uptake). Sver. Lantbruksuniv., Skogsfakta 28.

_____. 1986a. Effects of planting and scarification on water relations in planted seedlings of Scots pine. Stud. For. Suecica 173.

_____. 1986b. Water and nutrient uptake in relation to regeneration success. IUFRO Working Party S1.05-12, Grande Prairie, Alta. - Dawson Creek, B.C.

_____. 1987. Effects of site preparation on the development of planted seedlings in northern Sweden. IUFRO Working Party S1.05-12, Rovaniemi, Finland.

Örlander, G. and K. Due. 1986a. Water relations of seedlings of Scots pine grown in peat as a function of soil water potential and soil temperature. Studia Forestalia Suecica 175.

_____. 1986b. Location of hydraulic resistance in the soil-plant pathway in seedlings of *Pinus sylvestris* L. grown in peat. Can. J. For. Res. 16:115-123.

Örlander, G., G. Egnell, and S. Forsén. [1989]. Infrared thermography as a means of assessing seedling quality. Scand. J. For. Res. 4, 215-222.

Örlander, G. and P. Gemmel. 1989. Markberedning (Site preparation). Sver. Skogsvårdsförb. Tidskr. 3.

Örlander, G., G. Hallsby, and H. Sundkvist. [1989]. Överlevnad och tillväxt hos tall och gran, samt näringsförhållanden 23 år efter plantering på helplöjd resp. bränd tallhedsmark i Ångermanland (Survival and growth of pine and spruce, and nutrient relations 23 years after planting on a plowed and burned heath in Ångermanland). Sver. Lantbruksuniv., Inst. f. Skogsskötsel, Rapport 26.

Personal Communications

Dahlberg, A. Swed. Univ. Agric. Sci., Dept. Ecology and Conservation, Uppsala.

Lundmark-Thélin, A., Swed. Univ. Agric. Sci., Dept. Forest Soils, Uppsala.

Nordlander, G., Swed. Univ. Agr. Sci., Dept. Entomology, Uppsala.

Osberg, M., B.C. Ministry of Forest, Prince George.

Spittlehouse, D. B.C. Ministry of Forest, Victoria.

Zackrisson, O. Swed. Univ. Agric. Sci., Dept. Site Research, Umeå.

APPENDIX 1

Comparison of the climatic zones in British Columbia and Sweden using the Köppen-Geiger system of climate classification. After Strahler (1975).

Key to letter code designating climate regions:

First letter

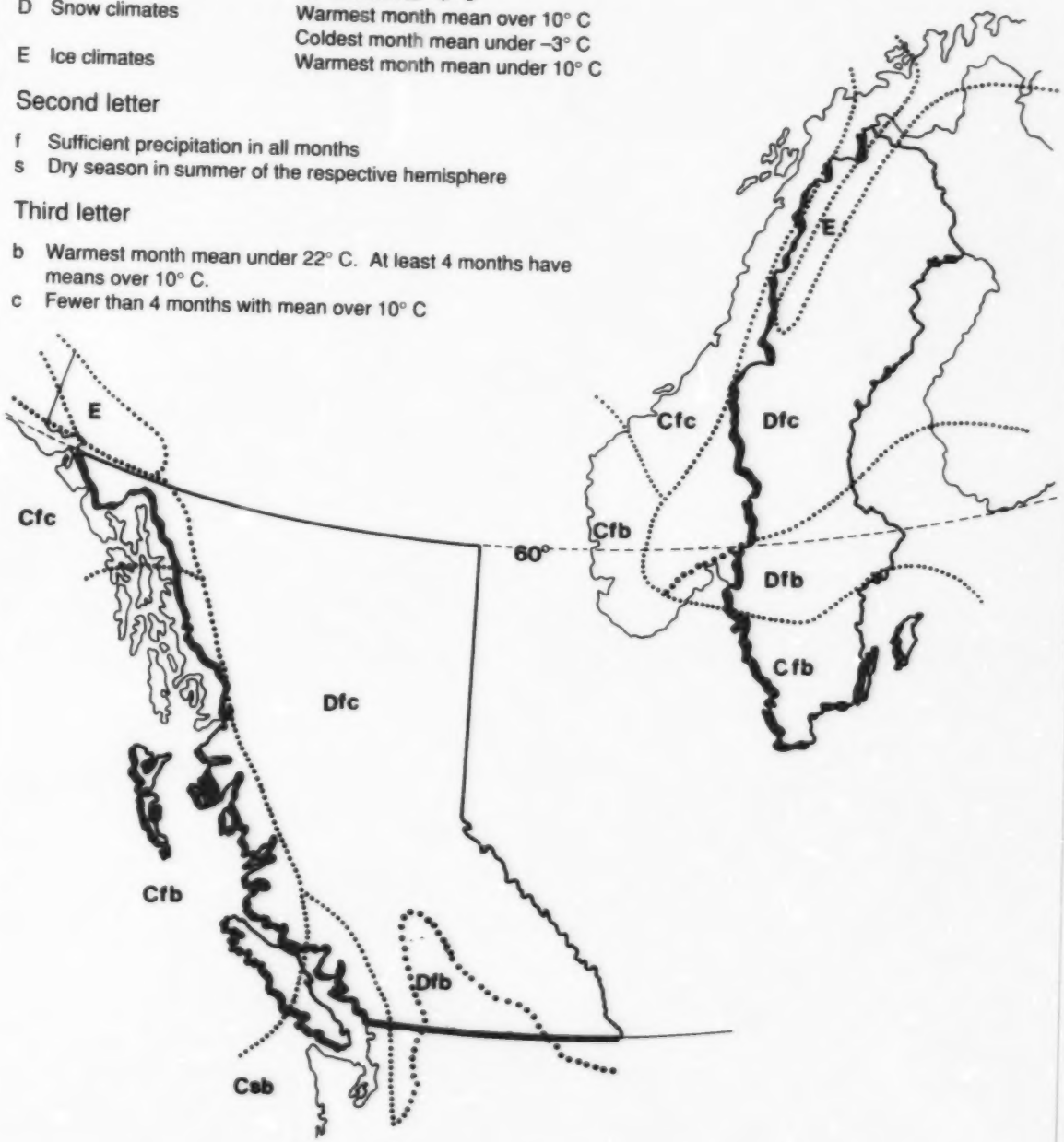
C	Warm temperate climates	Mean temperature of coldest month: 18° C down to –3° C
D	Snow climates	Warmest month mean over 10° C Coldest month mean under –3° C
E	Ice climates	Warmest month mean under 10° C

Second letter

- f Sufficient precipitation in all months
- s Dry season in summer of the respective hemisphere

Third letter

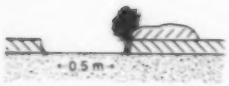
- b Warmest month mean under 22° C. At least 4 months have means over 10° C.
- c Fewer than 4 months with mean over 10° C



APPENDIX 2

Schematic descriptions of site preparation methods.

No site preparation



Patch scarification

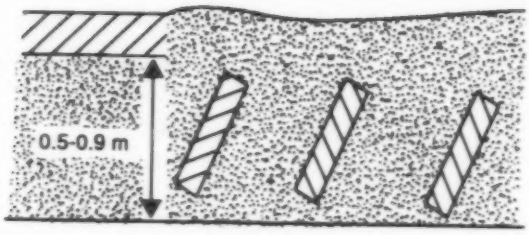
Disc trench

Mineral soil mound

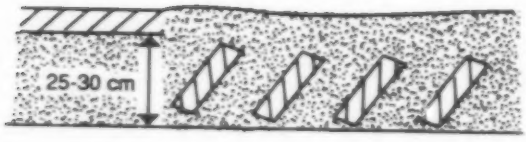
Inverted humus mound

Tilt plow

Terrace plow
(No longer used)



Deep plowing



Complete plowing